

**NASA  
Technical  
Memorandum**

**NASA TM-100336**

**IPS GUIDESTAR SELECTION FOR STELLAR MODE  
(ASTRO)**

**By Larry Mullins and Lewis Wooten**

**Systems Analysis and Integration Laboratory**

**June 1988**

**(NASA-TM-100336) IPS GUIDESTAR SELECTION  
FOR STELLAR MODE (ASTRO) (NASA) 134 p  
CSCL 17G**

**N88-27181**

**Unclas  
G3/04 0156606**



**National Aeronautics and  
Space Administration**

**George C. Marshall Space Flight Center**

1. REPORT NO. NASA TM-100336		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE IPS Guidestar Selection for Stellar Mode (ASTRO)				5. REPORT DATE June 1988	
				6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Larry Mullins and Lewis Wooten				8. PERFORMING ORGANIZATION REPORT #	
9. PERFORMING ORGANIZATION NAME AND ADDRESS  George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS  National Aeronautics and Space Administration Washington, D.C. 20546				13. TYPE OF REPORT & PERIOD COVERED  Technical Memorandum	
				14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES Prepared by Systems Analysis and Integration Laboratory, Science and Engineering Directorate					
16. ABSTRACT  This report describes how guide stars are selected for the Optical Sensor Package (OSP) for the Instrument Pointing System (IPS) when it is operating in the stellar mode on the ASTRO missions. It also describes how the objective loads are written and how the various roll angles are related; i.e., the celestial roll or position angle, the objective load roll angles, and the IPS gimbal angles. There is a brief description of how the IPS operates and its various modes of operation; i.e., IDOP, IDIN, and OSPCAL.					
17. KEY WORDS  Instrument Pointing System (IPS), Objective Loads, Guide Star Selection, Optical Sensor Package (OSP), IDOP, IDIN, OSPCAL, Roll Angles			18. DISTRIBUTION STATEMENT  Unclassified - Unlimited		
19. SECURITY CLASSIF. (of this report) Unclassified		20. SECURITY CLASSIF. (of this page) Unclassified		21. NO. OF PAGES 136	
				22. PRICE NTIS	

## ACKNOWLEDGMENT

We would like to express our sincere appreciation to Anthony (Tony) Lavoie, EL54, the MSFC systems engineer for the IPS who willingly gave so much of his time and expertise on the IPS systems to patiently and painstakingly explain to us, especially during our early days in working on this system, how the various systems work and who is diligent in making sure that we always have and are using the latest and most correct measurements and parameters in our software when searching for guidestars and generating objective loads. This has been especially important to us in view of the fact that this system was built in France and Germany and the original engineers were unavailable to us for consultation.

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## TECHNICAL MEMORANDUM

### IPS GUIDESTAR SELECTION FOR STELLAR MODE (ASTRO)

#### I. INTRODUCTION

The Instrument Pointing System (IPS) has been built under contract by Dornier of Germany for ESA and supplied to NASA as a part of the Spacelab system. It is to be flown for the first time in "Stellar Mode" on the ASTRO Mission. An integral part of the IPS is the Optical Sensor Package (OSP) which is mounted on the IPS and contains three star trackers, one boresighted with the IPS science package and the other two skewed at 12 deg angles from the boresight direction for the ASTRO mission. The purpose of the OSP is to do optical alignments or determinations of the IPS pointing direction using known stars.

It is desired that prior to each pointing operation the IPS be aligned using known guidestars. The responsibility for selecting these guidestars has fallen to the MSFC Mission Planning and Operations Team. The activity of "selecting the guidestars" also involves developing the "objective loads" for each of the selected guidestars. The "objective load" is a set of information which is loaded onto the on-board computer which tells the IPS "where to point" in order to perform the required alignment.

The purpose of this document is to describe how the candidate stars for the IPS alignments are identified. This set of candidate stars will be called the IPS guidestar catalog. Some details in the definition of the objective loads are also provided. Finally, there is also some discussion on determining the IPS gimbal angles (EL,XL,RL) given the Orbiter attitude (P,Y,R) and the desired inertial orientation of the IPS ( $\alpha_s, \delta_s$ , Roll).

Section III of this document is included here only to give the mission planning engineer an approximate idea of how the star tracker hardware operates. Most of this information was extracted from Reference 3 and the engineer should use that document for an authoritative description of the hardware and its operation. Understanding every detail of the operation of the hardware is not necessary for the job of selecting guidestars and writing objective loads but it may be useful to know a little of how the instrument works.

#### II. SOURCE OF STARS

The source of stars for developing the IPS guidestar catalog is the Skymap Star Catalog prepared for the Goddard Space Flight Center by the Computer Sciences Corporation in December 1977. Version 3.0 of this catalog contains 248,727 stars equal to or greater in brightness than 9th magnitude. The star positions are given in terms of right ascension and declination with respect to the epoch 2000.0. There are 135 descriptive or qualifying words of data for each star on that catalog. These are defined and described in detail in Reference 1.

This entire catalog of stars, having but 34 of the 135 qualifying words, has been condensed for use in mission planning and is now resident on the MIPS 4 computer at MSFC. The disc, directory, and file name on which this catalog resides may change from time to time. At the writing of this document it is on Disk \$PMISB: [SKYMAP] SKYMAP.V30;1. A description of this can be found in Reference 2. This condensed Skymap Star Catalog is the starting point for developing the IPS Guidestar Catalog. Table 1 defines the variables on this catalog. Reference to the original catalog will give an expanded definition of these variables.

TABLE 1. DESCRIPTION OF SKYMAP VARIABLES

SKYMAP V3.0 MIPS 4, DISK\$PMISB: [SKYMAP]SKYMAP.V30;1				
Master Catalogue Word #	VAX Catalogue Word	(Byte)	Type	Description
-	1	1	I	Next higher RA index number
-	2	5	I	Next higher DEC index number
-	3	9	I	Next lower RA index number
-	4	13	I	New lower DEC index number
2	5	17	I	SKYMAP number
8	6	21	A	Star name
9	7	25	A	Star name
10	8	29	A	Star name
11	9	33	A	Star name
12	10	37	A	Star name
13	11	41	R	Right ascension, standard epoch
14	12	45	R	Declination, standard epoch
15	13	49	R	Error in standard epoch position
25	14	53	R	Proper motion in right ascension
26	15	57	R	Proper motion in declination
27	16	61	R	Precession in rt. ascension
28	17	65	R	Precession in declination
31	18	69	R	U magnitude
33	19	73	R	B magnitude
34	20	77	R	V magnitude
35	21	81	I	B, V magnitude derivation flag
36	22	85	R	Photovisual magnitude
37	23	89	R	Photographic magnitude
38	24	93	I	Photovisual-photographic presence flag
42	25	97	I	Spectral class
43	26	101	I	Luminosity class
44	27	105	I	Peculiarity code
45	28	109	I	Spectral type source flag
70	29	113	I	Variability type code
72	30	117	R	Bright/dim magnitude difference
73	31	121	I	Variable magnitude type flag
76	32	125	R	Separation, multiple star
77	33	129	R	Difference in brightness of
79	34	133	R	Distance to catalogue nearest neighbor

### III. THE IPS AND THE STAR TRACKERS IN THE STELLAR MODE

The IPS on ASTRO will be used in the stellar mode. In this mode, the two off-axis star trackers are mounted on the OSP at 12 deg angles from the IPS boresight. The dihedral angle formed by the boresight tracker and each of the two off-axis trackers is 180 deg. The entire IPS assembly can rotate 360 deg about the boresight; i.e., about the science star being observed as illustrated schematically in Figure 1.

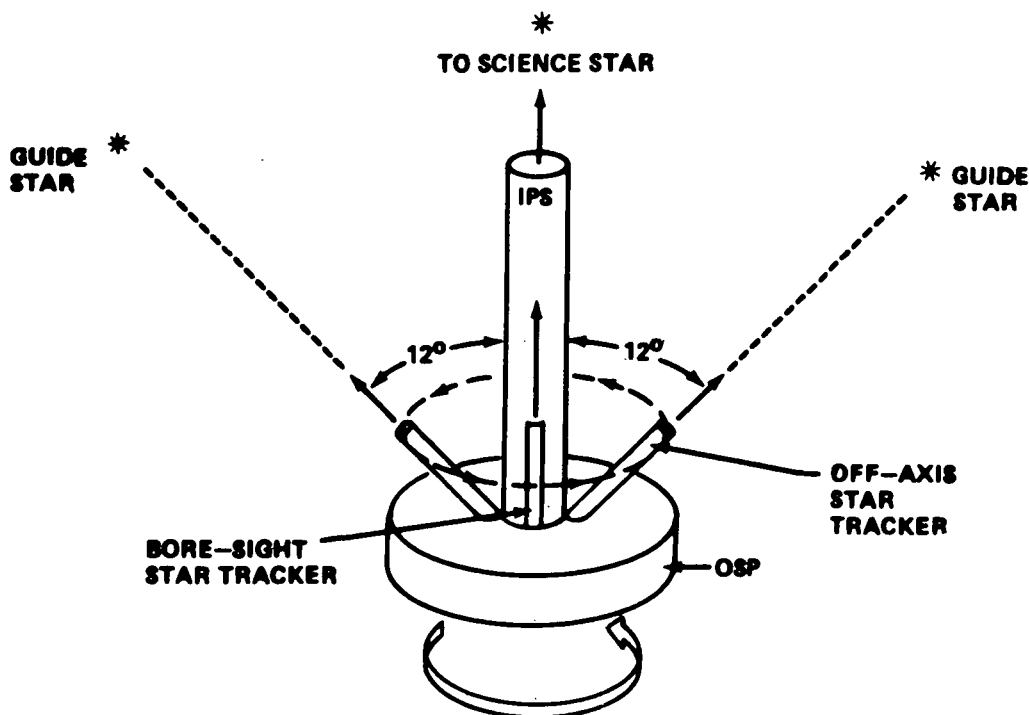


Figure 1. Schematic of IPS in stellar mode (IPS can rotate 360 deg about boresight).

The actual physical layout of the IPS instrument cluster on ASTRO-1 is shown in Figure 1A. In its cradle position in the payload bay, the instrument cluster is pointing to the rear of the orbiter. The physical mounting of the IPS on ASTRO-1 has mechanical stops which cause the gimbal roll freedom to be limited to  $\pm 180$  deg from the cradle position. The Orbiter body coordinate system shown in Figure 1A with axes denoted by  $(x_o, y_o, z_o)$  is the same system as the BY-system referenced in section 1.6 of Reference 8. Reference 8 is the authoritative document on all IPS coordinate systems and IPS coordinate system transformations. That document should be consulted when any question concerning coordinate systems or their transformations arises.

Each of the three star trackers has an approximately square field-of-view (FOV) whose dimensions are approximately  $2^\circ.21$  by  $2^\circ.21$ . Actually each star tracker FOV is unique in dimension which is determined by measurements made on each instrument. Physically the star tracker is composed of a set of visual optics which focus starlight (photons) on a photocathode which in turn emits electrons which, in turn, are focused

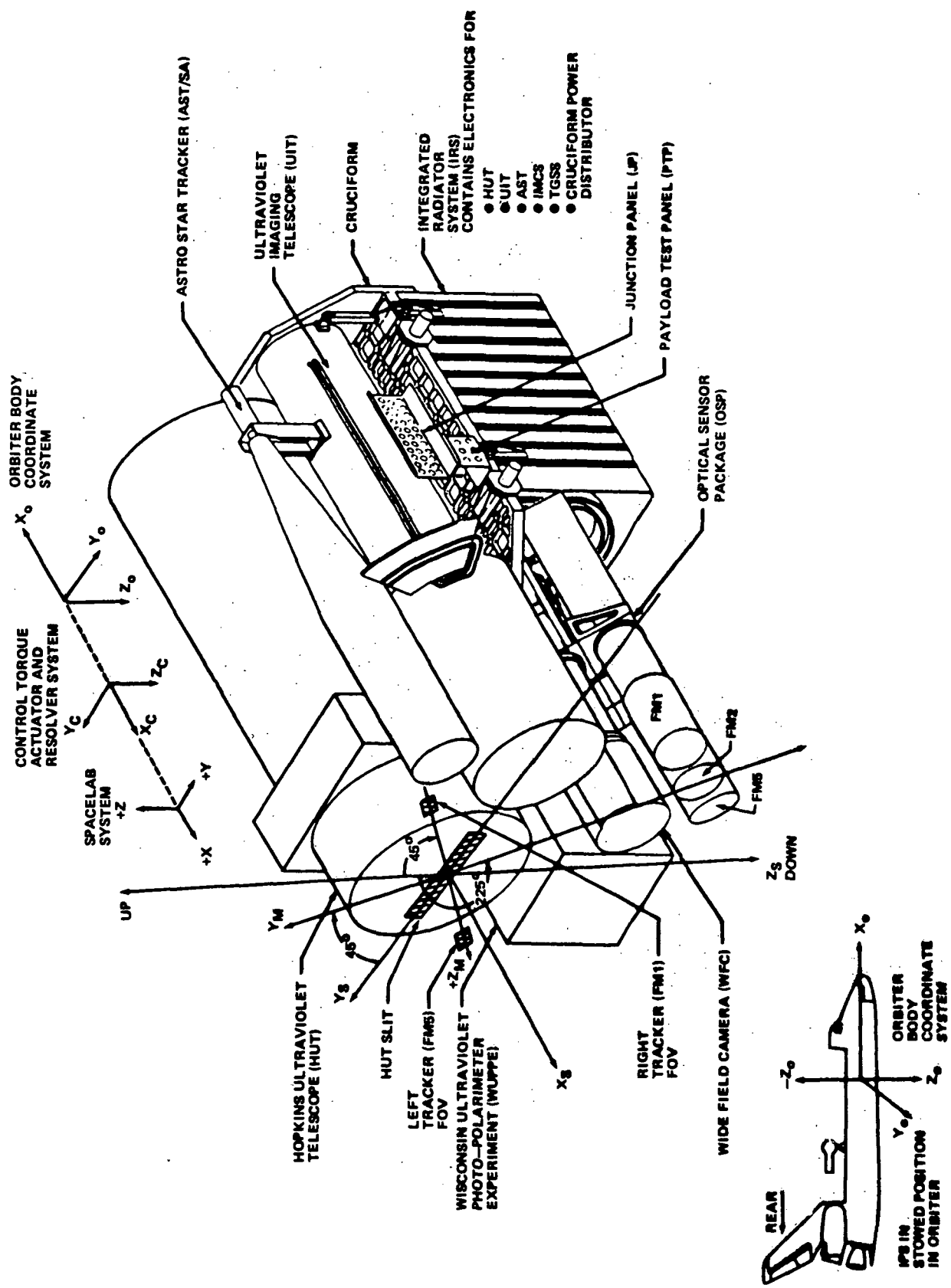


Figure 1A. IPS and OSP configuration for ASTRO-1 in its stowed position.

by an electromagnetic lens onto an electron detector (counting device). This electromagnetic lens and electron detector is called an Image Disector Tube (IDT) which is manufactured by ITT. The entire star tracker is packaged by SODERN of France for Dornier of Germany who integrated it with the IPS. This device is shown schematically in Figure 2.

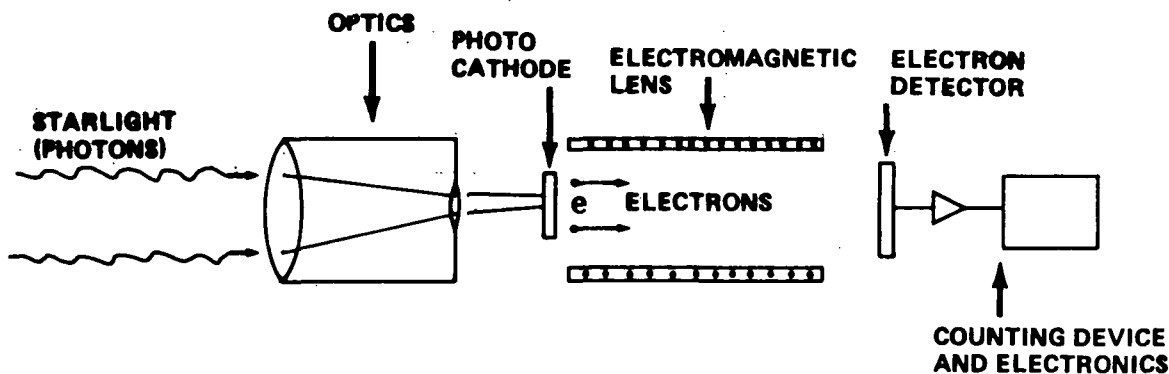


Figure 2. Schematic view of star detector.

The optics of this detector maps each point of light in the FOV of the star tracker onto a unique point on the photocathode. The electromagnetic lens of the IDT, in turn, scans each point of the photocathode emitting electrons and focuses them onto the electron detector. Electrons hitting the electron detector constitute a current which is digitized to a count rate proportional to the star brightness or magnitude.

The electromagnetic lens has two deflection coils in it corresponding to the Y and Z directions inside the tube. The magnitude of the currents in these coils, which vary in a way proportional to the various points on the photocathode which are being imaged, are called the electrical coordinates of the FOV or the Electrical Coil Coordinates (ECC). There is a linear transformation which converts the electrical coordinates of the FOV ( $Y_E$ ,  $Z_E$ ) into geometrical coordinates of the FOV ( $Y_G$ ,  $Z_G$ ).

The coefficients of this transformation are initially determined by ground calibration. This is done with the assistance of a calibration device called the Local Optical Reference Device (LORD) which provides a grid of 396 lighted points in 20 rows and 20 columns across the approximately  $2^\circ.2$  by  $2^\circ.2$  FOV, each pair of points being separated by  $6'49''$  as shown in Figure 3. This device is mounted in front of the optics and the 396 points, which are etched into a clear plastic-like sheet, are illuminated from the sides by two LEDs which can be switched on and off. When turned on, these lights shine through the optics onto the photocathode simulating a star background of 396 evenly distributed points of light on an approximately square FOV. The brightness of each of these points is equivalent to a star between 3rd and 4th magnitude. The wave length of the light from the LEDs is  $5830 \text{ \AA}$  which is in the yellow part of the visible spectrum. (There is a selected 3 of these points which will be referred to as "Master LORD Points" used in ground calibrations and on-board in rough track mode.)

There is an electrically controlled instantaneous field-of-view (IFOV) of approximately  $2.5'$  diameter which, starting at the upper left hand corner (in the IDIN mode) (negative Y and negative Z coordinates) sweeps across the FOV horizontally in increasing Y in a sort of raster scan. Actually the IFOV sits in one position for a

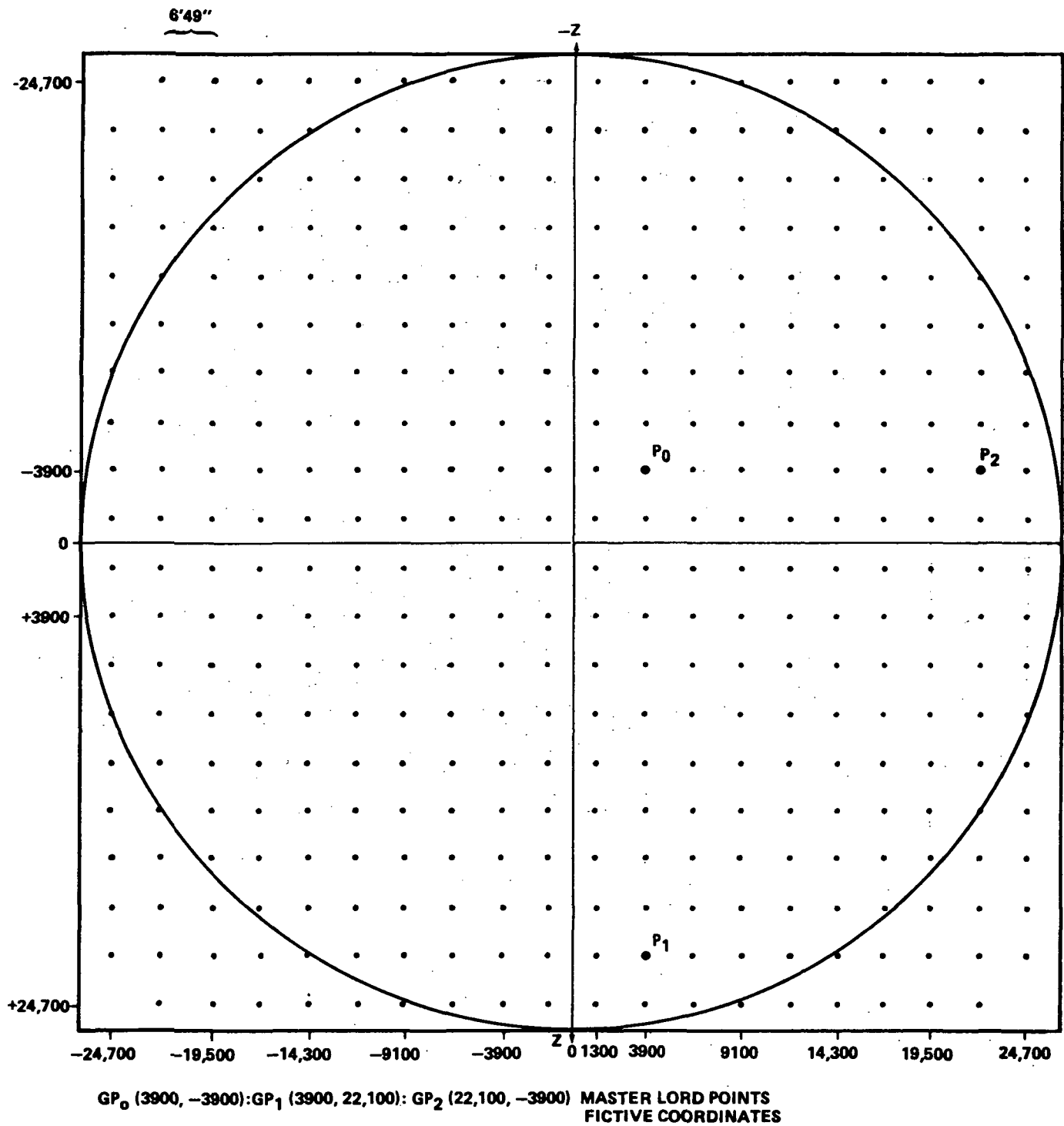


Figure 3. Square  $2.2^\circ \times 2.2^\circ$  FOV of startracker showing 396 LORD points and their geometric coordinates.

small amount of time (called the dwell time and equal to 5.673 ms. in the scan mode) counting photons. It then moves horizontally about 2' (less than the full IFOV) and then stops and counts again for the dwell time. It continues this until it completes a full line across the FOV. It then drops down (increments Z coordinate) about 1.'4 (again less than the full IFOV) and starts across the next line horizontally making counts. This scan pattern is shown in Figure 4. It continues this until the entire FOV is scanned, which takes about 70 sec, unless it hits a point where the count rate of current position (N) minus the count rate at position (N-2) is higher than the threshold detection level; a count rate input by the user which is a function of the magnitude of the star being sought. (During this scan mode the LORD points are turned off; otherwise they would trigger the threshold detection level count rate.)

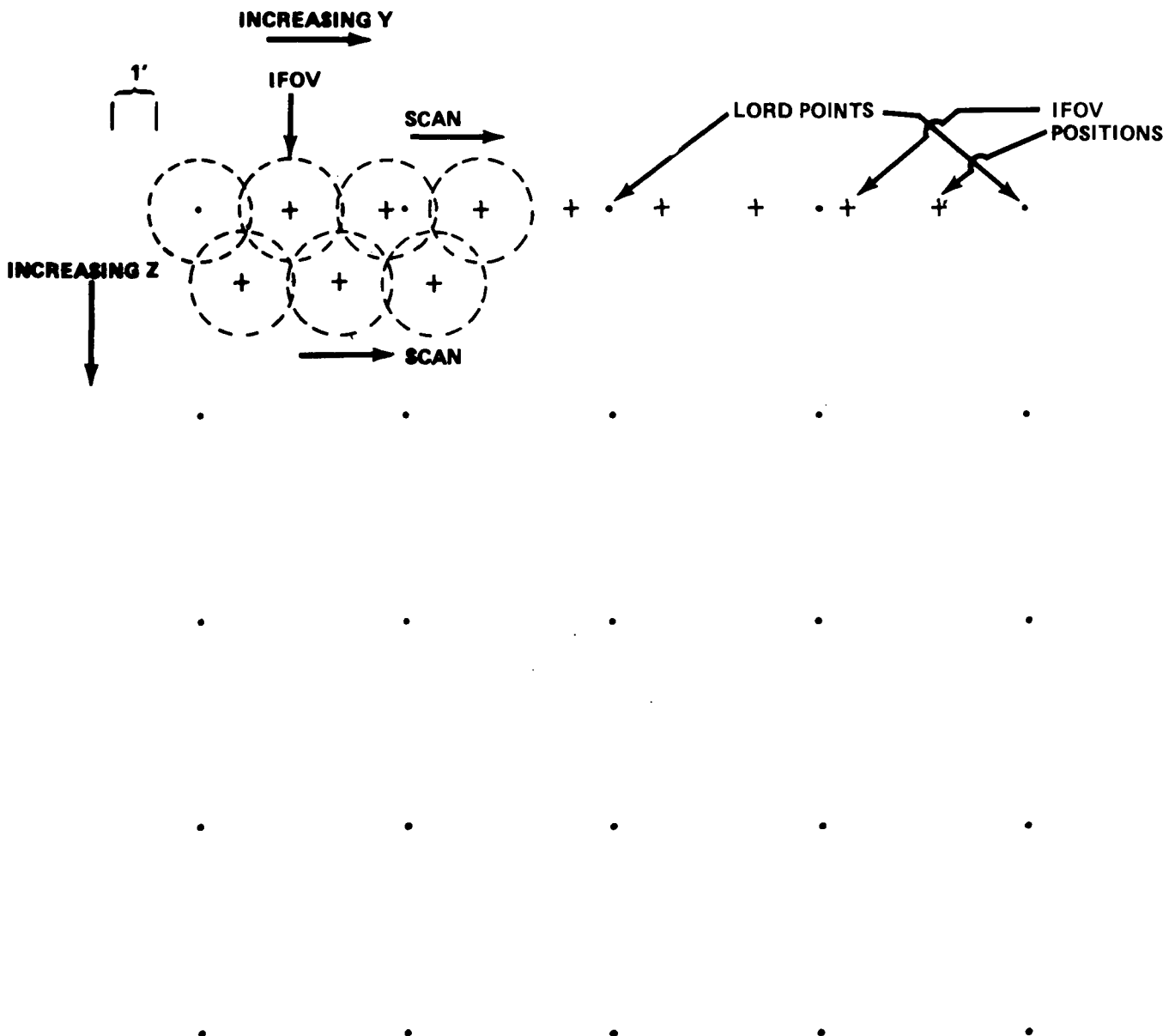


Figure 4. Scan pattern of IFOV in search mode.

In case of a detection, the star tracker leaves the scan mode (or search mode) and enters into a verification mode (or confirmation sequence). Detection is verified if the average of 6 independent measurements of the differential count rates between two adjacent but non-overlapping IFOV's exceeds the input count rate value. If the detection is not confirmed the scan continues. If the whole FOV is scanned with no detection confirmed, a flag of "unsuccessful search" is sent to the subsystem computer and the search mode stops until new commands are issued. If detection is confirmed the track mode is entered. The pattern for the track mode is shown in Figure 5 where there are four positions of the IFOV centered about the star in Y and Z in an energy balancing scheme. (The dwell time at each IFOV position in the track mode is 9.14 ms and the time required for one complete "cloverleaf pattern" is 40.41 ms.) The four IFOV's are positioned such that there are equal numbers of counts in the horizontal IFOV's and an equal number of counts in the vertical IFOV's. The center of these positions is then presumably the star position. The electrical coordinates of this position, as read from the currents in the deflection coils, are then converted into geometrical coordinates by the calibrated transformation equations.

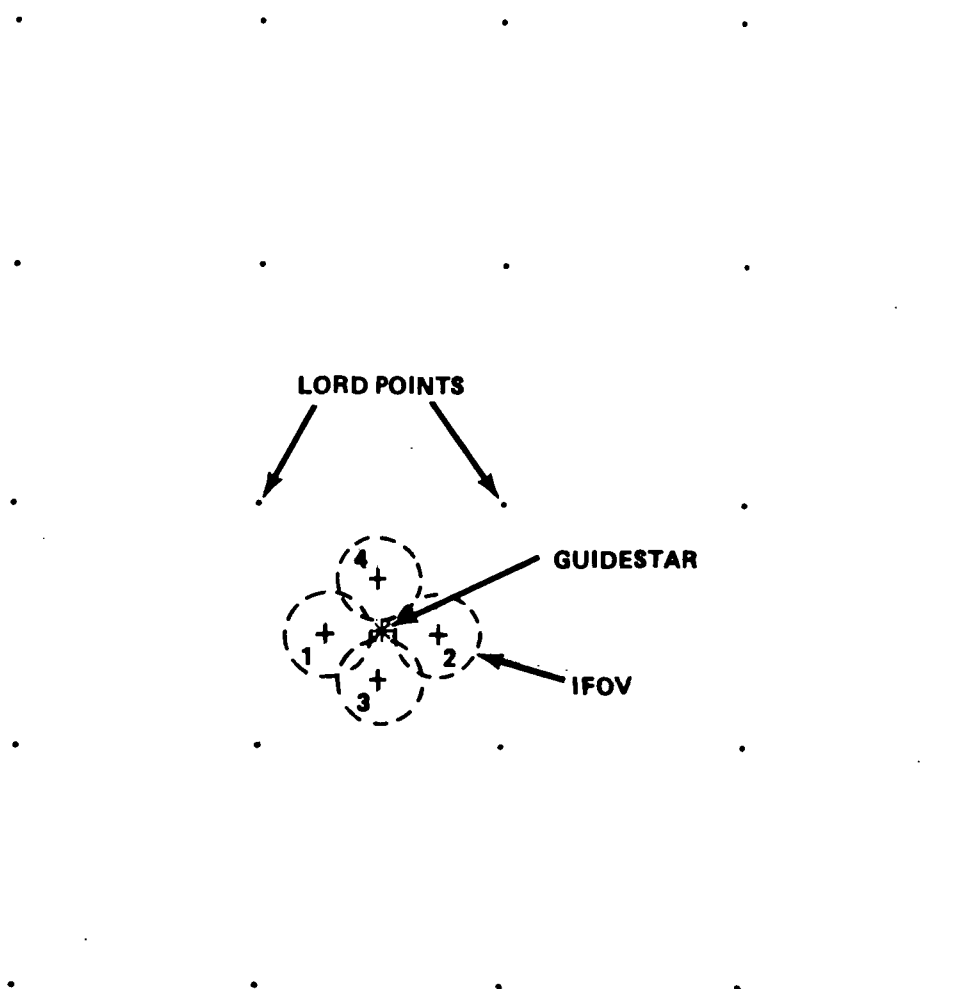


Figure 5. Track mode pattern of IFOV.



There are three tracking options called Coarse Track (CT), Rough Track (RT), and Fine Track (FT). The only difference in them is in the evaluation of the coefficients of the transformation which converts electrical coordinates into geometrical coordinates.

The CT option is used in the initialization of the sensor when the on-board computer (OBC) provides stored electrical and geometrical coordinates of the three Master LORD points and the coefficients of the transformation are computed from the stored values.

The RT option is similar to the CT model except here the 3 Master LORD points are tracked in real time to give new electrical coordinates and the coefficients of the transformation are then recomputed from these new values of electrical coordinates.

After star detection and confirmation, the three closest LORD points (Local LORD points) to the star are furnished and the star tracker then tracks the LLP for new electrical coordinates and a recalculation of the coefficients of the transformation for the FT mode.

The LORD points, illuminated by two LEDs, are off when the star tracker is searching for stars. The LORD points are switched alternately off and on when the instrument is to be calibrated. It is calibrated by tracking known positions of LORD points. In the tracking mode the star tracker alternately tracks the target and three LORD points; these are the Master LORD points in the RT mode and the three closest or Local LORD points in the FT mode. There is another operation called a transient phase or an intermediate tracking phase between the confirmation of a target and the switch from scanning to tracking modes. During this transient phase, the LORD points are tracked full time for 9 sec in 1 star track mode (IRT1) or 18 sec in 2 star track mode (IRT20,21,22). In the 1 star fine track transient phase (IFT1) the LORD points are tracked for 7 sec and in the 2 star fine track transient phase (IFT20,21,22), the LORD points are tracked for 13 sec. The purpose of this transient phase is to update the coefficients in the transformation equation between electrical and geometrical coordinates. During this transient phase the maximum total motion of the target must not exceed 0.8 IFOV or 120 arcsec to ensure that the target is not lost during this phase. Assuming that target velocity is constant for this phase, the average rate allowed for target movement is roughly 16 arcsec/sec in 1 track mode RT1 or 9 arcsec/sec in RT2 mode.

There are 15 different tracking modes in which the star tracker can operate. These are:

- CAL - LORD point calibration
- CT1 - 1 star coarse tracking
- RT1 - 1 star rough tracking
- FT1 - 1 star fine tracking
- CT2 - 2 star coarse tracking
- RT2 - 2 star rough tracking
- FT2 - 2 star fine tracking

The following modes are all transient or intermediate tracking modes:

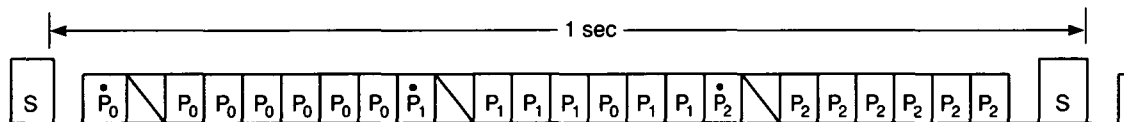
- IRT1 - 1 star intermediate rough tracking
- IFT1 - 1 star intermediate fine tracking

The following modes are all 2 star tracking transient modes:

IRT21 - star 1 intermediate rough tracking; star 2 rough tracking  
 IRT22 - star 1 rough tracking; star 2 intermediate rough tracking  
 IRT20 - star 1 and star 2 intermediate rough tracking  
 IFT21 - star 1 intermediate fine tracking; star 2 fine tracking  
 IFT22 - star 1 fine tracking; star 2 intermediate fine tracking  
 IFT20 - star 1 and star 2 intermediate fine tracking.

Page 94 of Reference 3 shows the timing of the tracking patterns for all of the tracking modes of the star tracker. As discussed on page 79 of Reference 3, the basic period of all of the tracking modes is a 1 sec interval of time which is broken down into 24 periods of 40.41 msec with a sync pulse added for CPU setting. The patterns on page 94 of Reference 3 show how these 24 periods are allocated for each of the 15 tracking modes listed above. During each of the 24 periods of 40.41 msec, the tracker puts the IFOV in a "four leaf clover" pattern about the point being tracked (as shown in Fig. 5 of this document) with the dwell time at each clover-leaf position being 9.14 msec; thus, in the basic 1 sec time interval, the tracker will do  $24 \times 4 = 96$  positions of the IFOV in 24 clover-leaf positions.

To illustrate the timing and tracking patterns, consider the intermediate 1 star tracking mode (IRT or IFT) shown on line 4 of page 94 of Reference 3 and reproduced here.



where  $\dot{P}_i$  = LORD point  $P_i$  off.      S = Sync Pulse  
 $P_i$  = LORD point  $P_i$  on.

This pattern shows that  $P_0$  is tracked once with the LED off (and when we say that a point is "tracked" we mean that the IFOV is placed in a four-leaf clover pattern about in in 40.41 msec), there is one blanked out tracking period, and then  $P_0$  is tracked six times with the LED on for a total of 8 tracking periods (8 four-leaf clovers). This pattern is then repeated for  $P_1$  and then again for  $P_2$ , making up the basic cycle of 24 tracking patterns. Adding the sync pulse makes up the basic 1 sec tracking cycle. The whole procedure is repeated for a total of 9 times in 9 sec in this transient tracking mode. The average values obtained for the ECC of the LORD points are then used to update the transformation equations between the electrical and geometrical coordinates. [The LORD points used above are the master LORD points in the intermediate rough tracking mode (IRT1) or the local LORD points in the intermediate fine tracking mode (IFT1)]. When this mode is completed, the tracker will switch to the continuous tracking phase which will be RT1 from IRT1 or FT1 from IFT1.

After the tracking mode starts full time, the tracker alternately tracks the target star and three LORD points. Those are the Master LORD points for the

rough track mode and the Local LORD points for the fine track mode. The LORD points are turned off while the star is being tracked and are alternately off and on while they are being tracked.

In the continuous tracking phase, a much higher target rate of motion can be tracked. The allowed motion here is approximately 300 arcsec/sec for RT1/FT1 and RT2/FT2.

The timing of the tracking pattern RT1 or FT1, shown on page 94 of Reference 3, shows that Po is tracked once with the LORD off and then once with the LORD on. The guidestar is then tracked 6 times. This is repeated then for P1 and the guidestar again six times; then P2 and the guidestar again six times. This gives a total of 24 tracking patterns (clover-leaves) plus a sync pulse again in a 1 sec time span. The tracking patterns for all of the different tracking modes can be seen on page 94 of Reference 3.

Although the full FOV of the tracker is a minimum of  $2^{\circ}.23$  ( $\Delta Y$ ) by  $2^{\circ}.24$  ( $\Delta Z$ ), and can be larger for specific models, and it can scan, acquire and rough track in this area, it can fine track only inside the LORD point grid (FHST model dependent) because of the dependence upon the LORD points. Therefore, the selection of guide stars should be restricted to the smaller area although the larger area will be searched for spoiler stars.

In the IDOP mode the initial search is not necessarily started in the upper left-hand corner of the FOV but at whatever Y-Z coordinates are specified by the operator. Once the start point is specified, however, the search pattern is then the same as in the IDIN mode, i.e., it scans in increasing Y and increments in increasing Z. This was designed to shorten the guidestar acquisition time by starting the search in the vicinity of the expected star position.

In addition to the above described characteristics, each unit also has a Bright Object Detector (BOD) which is a solar cell. It is a safety device which will automatically close the shutter if a too bright object, such as the Sun, approaches the FOV of the star tracker. As a note of caution, the first issue of Reference 3 stated that it is mandatory to move the entire IPS to get this bright object out of the FOV within 2 min of time, otherwise the shutter blade could be overheated.

All of this is explained in more detail in Reference 3. The calibration curves are contained in Reference 4. Each individual star tracker is a unique device with its own performance characteristics. These are detailed in six separate documents in Reference 4. On the ASTRO-1 mission these three instruments are FM1, FM5, and FM2. FM1 is in the left skewed position on the IPS, FM2 is in the boresight position, and FM5 is in the right skewed position.

According to the calibration curves in Reference 4, these trackers cannot detect any star dimmer than 9th magnitude (count rate goes to zero) and stars dimmer than 8th magnitude should not be used for operational stars. Also, no star brighter than 2nd magnitude can be used because the intensity of the radiation from these stars will saturate the detectors.

All three star trackers are integrated onto the IPS in a mode illustrated by Figure 1. Looking along the boresight, the FOV and potential FOV is illustrated in Figure 6. Its projection onto the celestial sphere when the IPS is observing a star at position ( $\alpha$ ,  $\delta$ ) is shown in Figure 7.

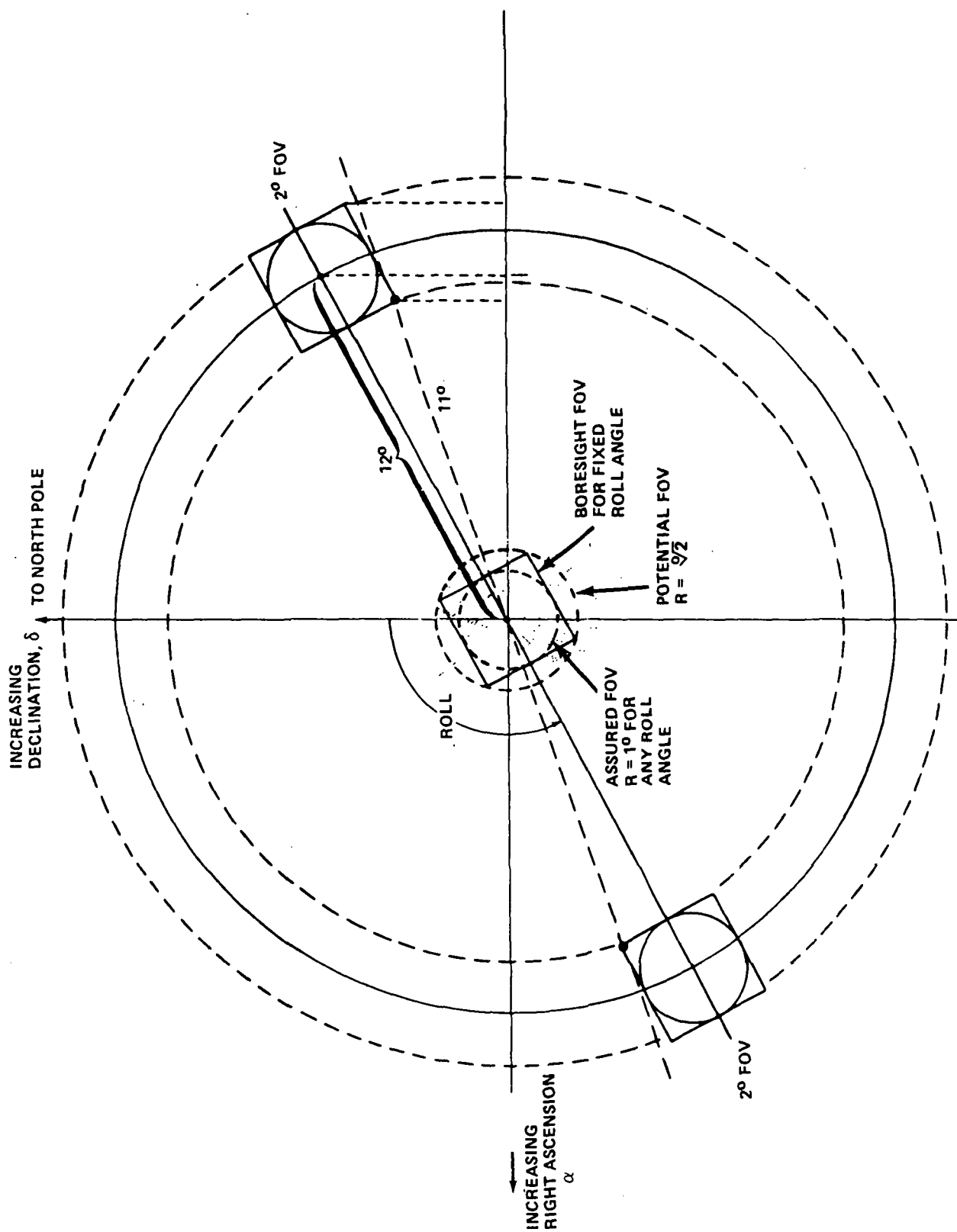


Figure 6. Boresight view of IPS in stellar mode looking from Earth toward the celestial sphere.

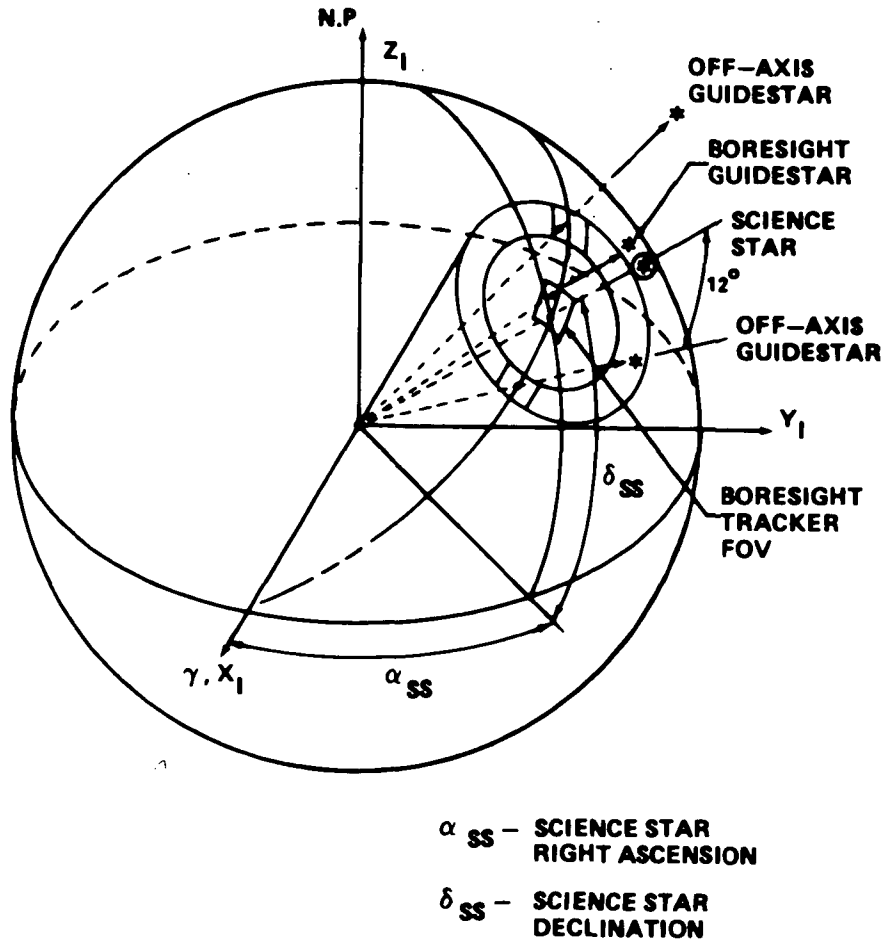


Figure 7. FOV of three star trackers projected onto the celestial sphere.

One might reasonably ask the question, "How many stars of 8th magnitude or brighter could one expect to find, on average, in any 2 deg x 2 deg FOV on the celestial sphere?" or, "How many stars could be expected in a 2 deg wide annulus as illustrated in Figure 6?". According to data presented by Allen [5, p. 234], the average number of stars per square degree brighter than 8th visual magnitude is 1. Therefore, on the average, at any position on the celestial sphere, in a 2 deg x 2 deg square FOV, there should be 4 stars of 8th magnitude or brighter. An annulus 2 deg wide and centered 12 deg from an axis of rotation projected onto a sphere subtends 0.003628 of the total celestial sphere or 150 square degrees. Thus, in such an annulus there should be, on average, 150 stars of 8th magnitude or brighter. It is known, however, that stars are not distributed uniformly on the celestial sphere so in some places there will be more and in some places less stars than the above quoted numbers.

The density of stars falls off approximately as  $1/e$  with decreasing magnitude (increasing brightness). Therefore, one might expect 1.5 stars of 7th magnitude or brighter in any 2 deg x 2 deg FOV or an average of 0.5 stars of 6th magnitude or brighter. Some of these stars, however, will be variable stars and thus unsuitable as operational stars. Also, according to Allen [5, p. 209], there are nearly 15,000 catalogued variable stars. This total number is approximately one-third the number of 8th magnitude or brighter stars in the sky, therefore, one can expect a considerable fraction of all stars considered as guidestars to be unuseable as operational stars because they will be variable. Thus, the previous estimates of the expected

number of stars to be found on average should perhaps be reduced by 25 percent or so to get the expected number of usable operational stars.

Before proceeding to the next section, we might say just a word about the calibration mode which is described on page 62 of Reference 3. This mode, which allows one to measure the electrical coordinates of any selected LORD point, is designed to check the drift of the electrical coordinates of the Master LORD points after major events such as transportation, environmental testing, launch, etc. This mode may also be considered as a self-check feature since all of the hardware assemblies and most of the software routines are activated by it.

#### IV. METHODS OF SELECTING GUIDESTARS

The method of selecting guidestars for the stellar mode is considerably different from the solar case. In some aspects, simpler; in others, more complicated. The primary difference is that in the solar case the guidestars are time dependent because the primary target, the Sun, is moving while in the stellar case the guidestars are not time dependent because the objects being observed, stars, are not moving. The only moving objects for the ASTRO-1 mission, may be comets, planets, or asteroids; but they, at different times and thus in different positions, will be treated as a number of different stars.

In the solar case there is only one science objective, the Sun, and therefore only one object for which guidestars must be selected. In the stellar case there are hundreds of science objectives (stars) and therefore hundreds of objects for which guidestar selection must be done (and objective loads written).

There are other differences also. In the solar case there can be only one unique bright guidestar in the FOV of the tracker (IDIN mode) for each roll reference update which characteristically is done only occasionally; maybe once a day. In the stellar case there can be as many as seven (7) stars in the FOV of each tracker (IDOP mode) and it is desired to do a reference update prior to each science star data take. In the case of up to seven stars in an FOV, the position of each star in the FOV must be known relatively accurately and there must be an objective load on the MMU for each science star. During the search and verification operation, the guide star will be identified by three tests; one is a brightness or count rate test, second is a position test, and third is an angular separation test between the star being sought and guidestars in one or both of the other two trackers.

##### A. Initial Search

For each science star to be observed, two searches for guidestars must be performed; one is a search of a circular region about the science star where the boresight tracker (BST) will be pointed, and second, is a search of an annular region varying between about 11 deg and 13 deg from the science star where the skewed trackers (SKT) will be pointed. This dual search must be carried out for each science star to be observed during the mission. Once a guidestar is identified, however, it is valid for all time in contrast to the solar mode where a guidestar can be used for only a few days during the year.

A potential guidestar in the boresight tracker must have a central angle between it and the science star of less than 1 deg to be assured of being available for any

roll angle and one in the annulus must have a central angle with the science star of between 11 deg and 13 deg. To account for misalignments in the mounting of the star trackers on the IPS, and slight variations in their FOV sizes, a search of a slightly larger boresight and annular region than the ideal is made. The ideal boresight region is  $\sqrt{2}$  deg but the search region is increased to  $\sqrt{2.0442}$ . The ideal annular region is between 11 deg and 13 deg but this range is increased 10.°78 to 13°22 to accommodate slight misalignments. The determination of stars in the exact FOV's will be made later.

The position of the stars in the annulus is measured by a position angle from North as depicted by Figure 8. By the law of cosines applied to the spherical triangle shown in Figure 8,

$$\begin{aligned} P. A. &= \cos^{-1} [(\cos \theta_2 - \cos \theta_1 \cos \theta_3) / \sin \theta_1 \sin \theta_3] \\ &= \cos^{-1} [(\sin \delta_g - \sin \delta_s \cos \theta_3) / \cos \delta_s \sin \theta_3] \end{aligned} \quad (1)$$

where  $(\alpha_s, \delta_s)$  and  $(\alpha_g, \delta_g)$  are the right ascension and declination of the science stars observed by the BST and the right ascension and declination of the guidestar, respectively. The angle  $\theta_3$  is given by

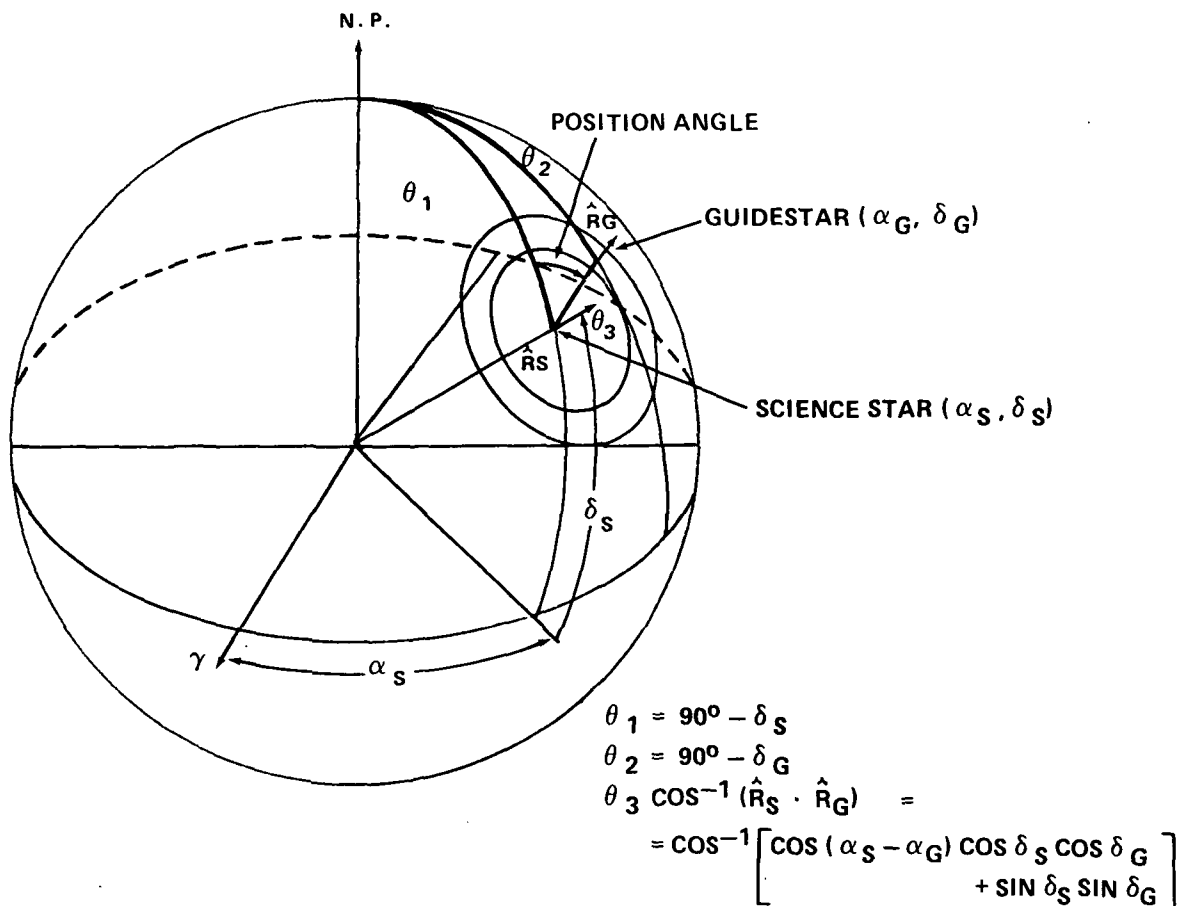
$$\theta_3 = \cos^{-1} (\hat{R}_s \cdot \hat{R}_g) = \cos^{-1} [\cos (\alpha_s - \alpha_g) \cos \delta_s \cos \delta_g + \sin \delta_s \sin \delta_g] . \quad (2)$$

Because equation (1) will only calculate the position angle, depicted in Figure 8, between  $(0, \pi)$ , the condition is imposed that if  $\alpha_g < \alpha_s$  then  $P. A. = 2\pi - P.A.$ . This will insure that  $P. A.$  is properly calculated in the range  $(0, 2\pi)$ .

The search for potential guidestars is made from the SKYMAP catalog. Figure 9 shows an overview of the flow of the search technique for the IDOP mode. The search shown in the first block of Figure 9 simply finds all stars in a boresight and in an annulus region about a given science star and then writes them onto two separate files (or as separate subjects on the same file) on which further processing will be done. Figure 9A shows the modification of this process for the IDIN targets. The details of the first search technique are shown in the flowchart of Figure 10. These first two files, denoted A1 and B1, will be used to do further processing in order to identify potential guidestars. They will also be used to identify spoiler stars for those potential guidestars. The computer program which does this is called GSOLP (for Guide Star Objective Load Program).

## B. Guidestar Characteristics

The stars used by the IPS star trackers as guidestars (also referred to as Bright Stars in the IDIN mode and Operational Stars in the IDOP mode) must have the following characteristics:



$$P. A. = \cos^{-1} \left[ \frac{\cos \theta_2 - \cos \theta_1 \cos \theta_3}{\sin \theta_1 \sin \theta_3} \right]$$

$$P. A. = \cos^{-1} \left[ \frac{\sin \delta_G - \sin \delta_S \cos \theta_3}{\cos \delta_S \sin \theta_3} \right]$$

$$ROLL = 2 \pi - P. A.$$

Figure 8. Definition of position angle of guidestar relative to science star.



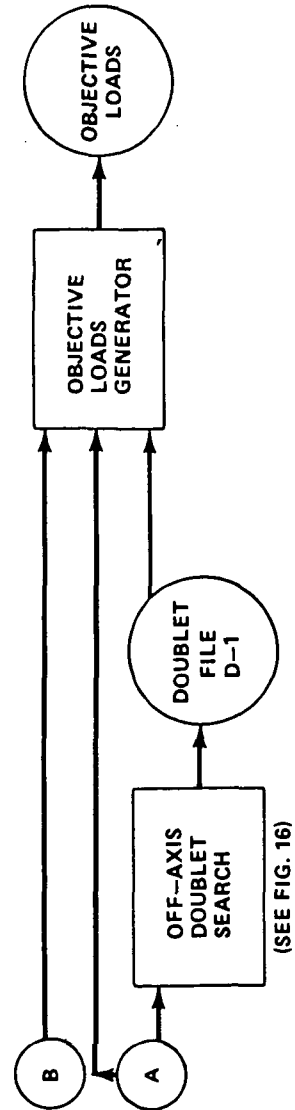
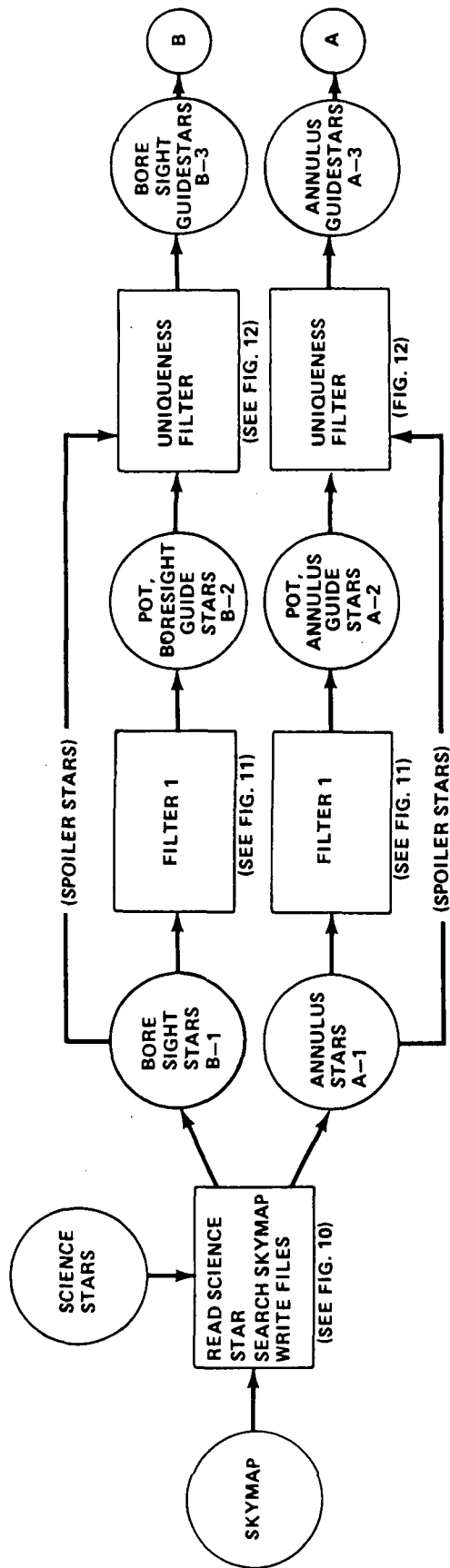


Figure 9. Overview of search technique for guidestars in the IDOP mode for stellar missions.

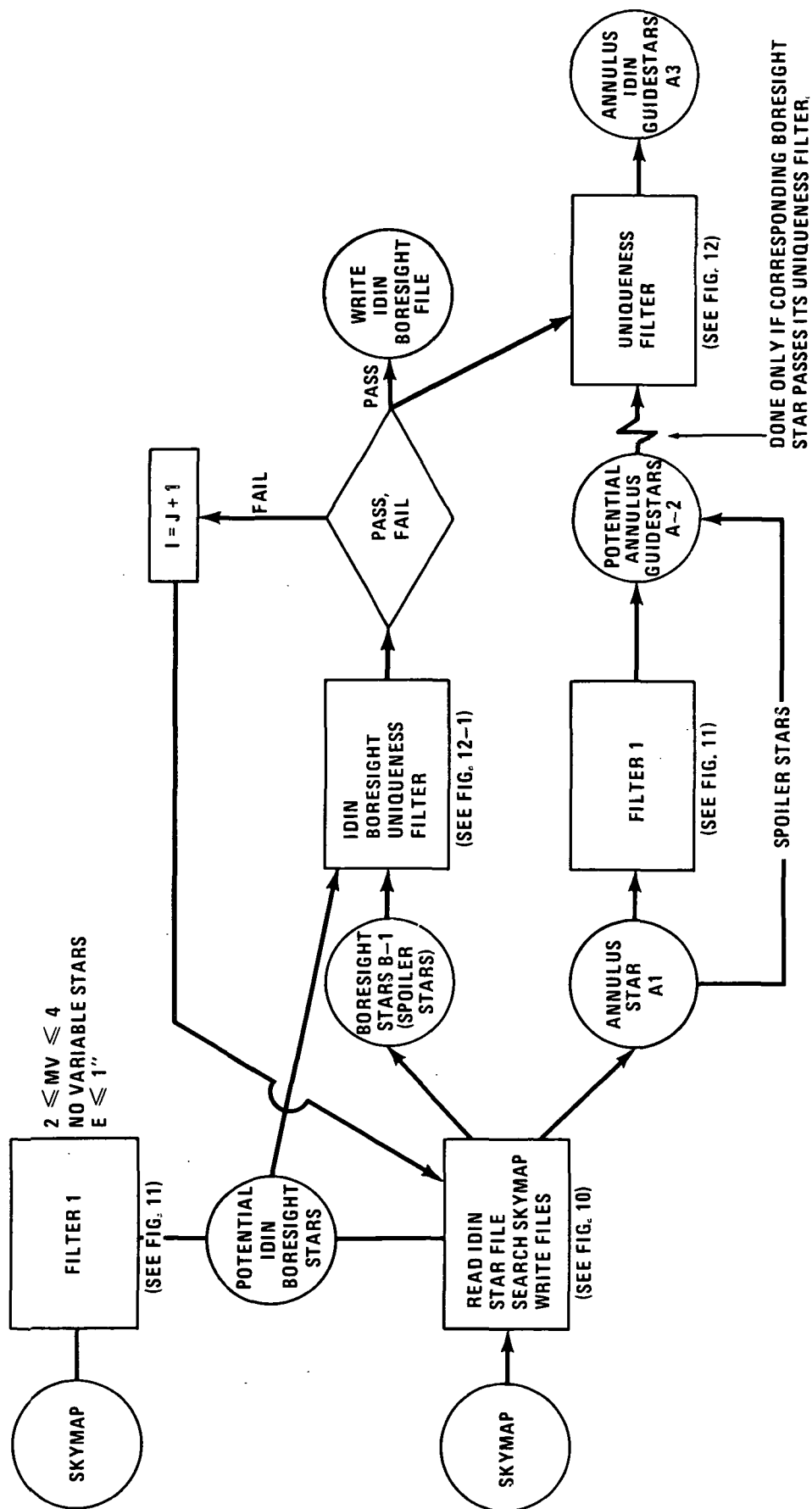


Figure 9A. Overview of search technique for guidestars in the IDIN mode for stellar missions.

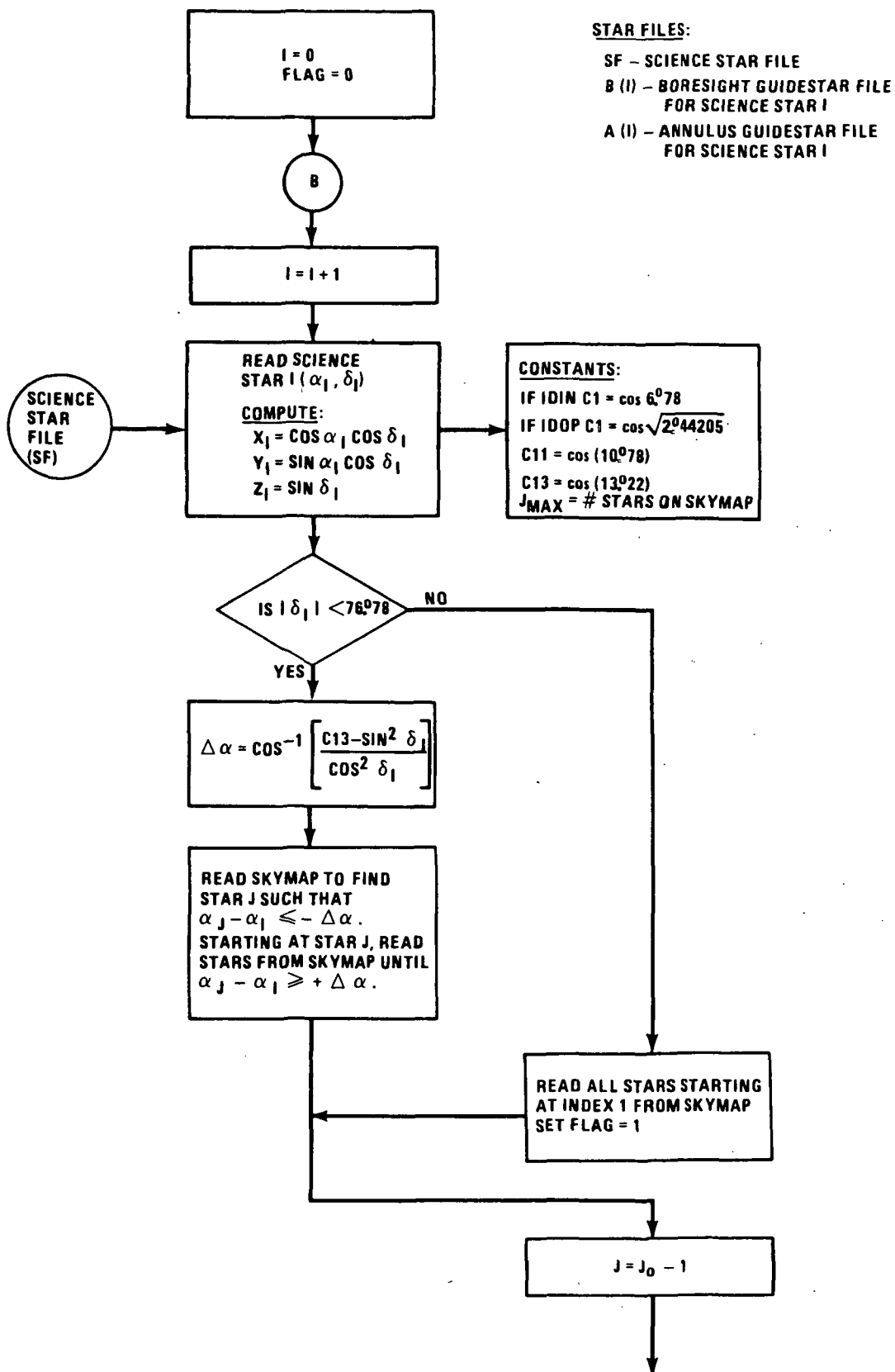
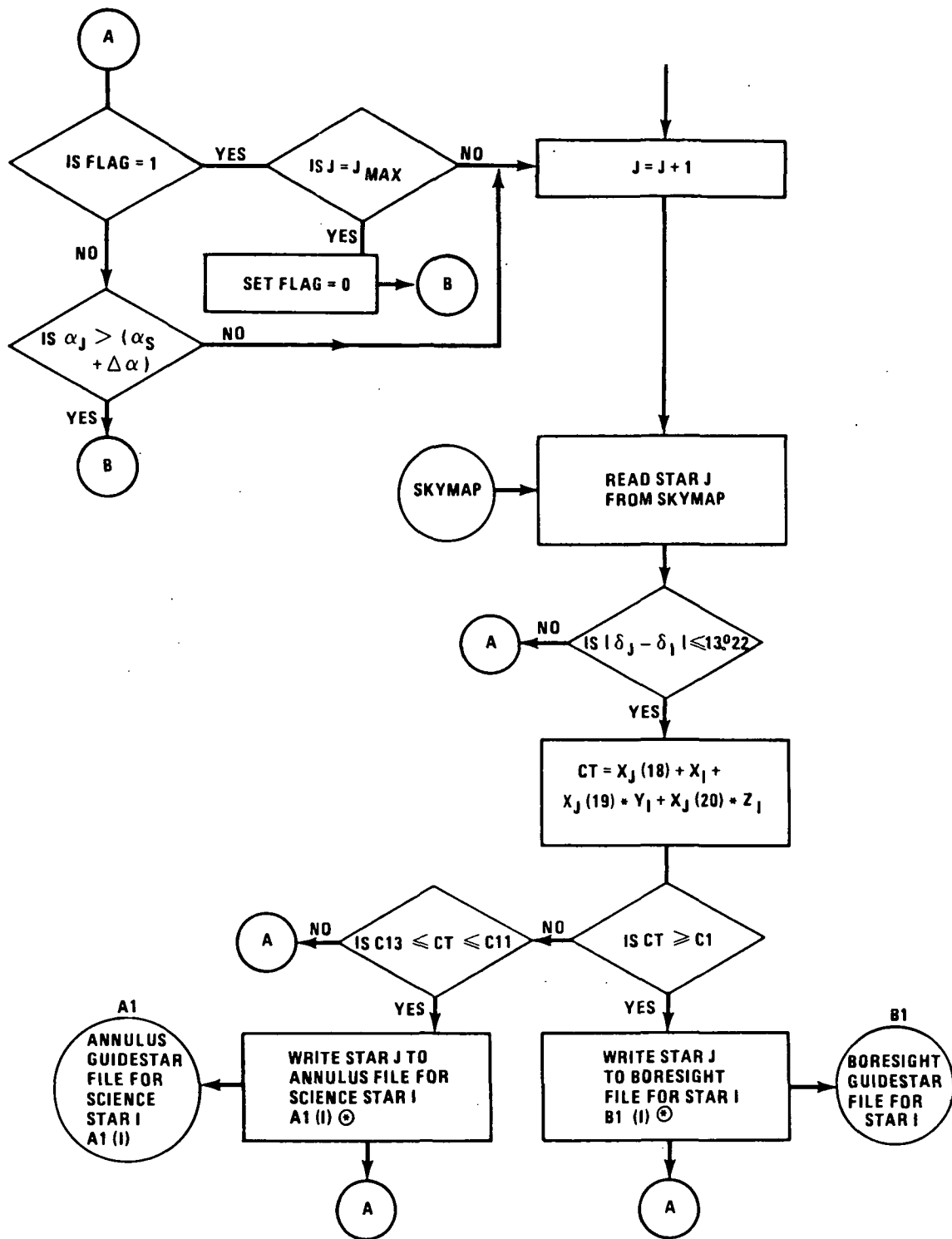


Figure 10. Initial guidestar search for stellar mode.



⊙ CALCULATE ROLL ANGLE AND MOATE COORDINATES AND ADD TO FILE.

Figure 10. (Concluded)

	<u>IDIN Mode</u>	<u>IDOP Mode</u>
o Visual magnitude range	2-4	2-8
o No variable stars		
o All star positions accurate to within 1".		

Stars possessing these characteristics are separated out by the Filter 1 shown in Figure 9 and written onto two other files called B2 and A2, representing potential guidestars. This Filter is shown in flowchart form in Figure 11.

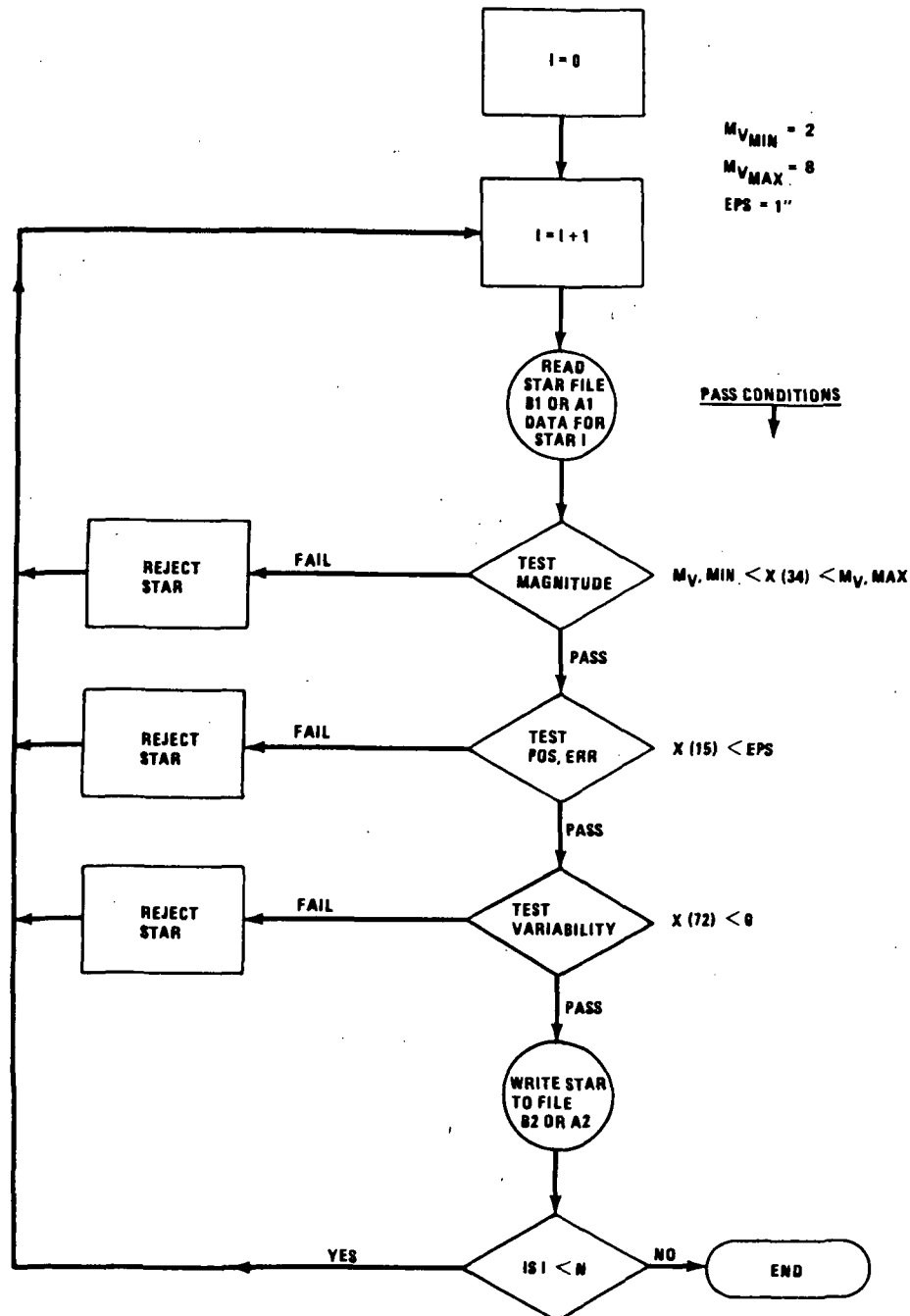


Figure 11. Filter 1 on original boresight and annulus stars.

The IDIN mode is conceptually different from the IDOP mode in that it is primarily used to provide initial orientation of the IPS and generally is not used as a science operation. In the IDOP mode, a science star will typically be centered in the boresight tracker and guide star(s) will be off-centered from the boresight. In the IDIN mode, the boresight tracker will be centered on a bright, unique guidestar with no other stars within a predefined visual magnitude (star tracker dependent; currently using 1) within a radius of  $6.^\circ78$ .

The way in which IDIN guidestars are selected is to take all bright stars ( $2 \leq M_v \leq 4$ ) from the SKYMAP catalog, filter out the variable ones and write the remaining ones on a file to be treated in the same manner as a science star file as shown by the flow in Figure 9A. A search about each of these stars can then be done to produce the A1 and B1 files of stars in the annulus and boresight regions, respectively, about each potential IDIN star.

The IDIN uniqueness criteria is then applied to the Potential IDIN boresight stars with the B1 file containing the spoiler stars. Any star that passes is then written to an IDIN boresight file and then the uniqueness filter for the annulus stars is applied to the appropriate set of annulus stars in the A2 file to produce any annulus IDIN guidestars which may be found.

### C. Uniqueness Criteria

There are different uniqueness criteria for the guidestars in the IDIN and IDOP modes. In the IDIN mode (an initialization search for guidestars), if the proposed guidestar has a magnitude of  $M_v$  then there can be no other star brighter than  $M_v + 1$  within  $6^\circ.78$  of the boresight region. In the annulus region there can be no such star within a width of  $2^\circ.44$  nor within a central angle of  $2^\circ.85$  in the roll direction (either way). This central angle of  $2^\circ.85$  in the roll direction converts into a roll angle of  $14^\circ.623$  about the boresight (half the tracker FOV subtends a roll angle at the boresight of  $\approx 5^\circ.227$ . See Appendix C for details of this calculation). The second uniqueness criterion in the IDIN mode is that there can be no other star within 4 visual magnitudes of the guidestar within an instantaneous FOV (IFOV) of  $3'$ .

In the IDOP mode (the operational mode), the first criterion listed above does not necessarily apply but the second one does. The reason that the first criterion does not necessarily apply is that in the IDOP mode the search does not necessarily begin in the upper left hand corner of the FOV as in the IDIN mode but at whatever position in the FOV the operator chooses. Thus, by proper choice of starting position of the search, an unwanted bright star in the FOV can possibly be avoided.

For the IDOP mode, however, there is a smaller uniqueness area which is applicable. This is discussed in section 3.5 and 3.6 of Reference 6. According to the test cases included in that reference (e.g., page 54), this uniqueness area is a square of side  $0^\circ.64$  centered on the guidestar; i.e., an area  $0^\circ.32$  in both vertical and horizontal directions from the guide star in which another star within 1.1 visual magnitudes of the guidestar cannot lie. This criteria has been included in the uniqueness filter shown in Figure 12, except here the uniqueness area is treated not as a square but as a circular region about the guidestar of radius  $0^\circ.32$ . (More severe criteria introduced late in the fall of 1985 increased the uniqueness area to  $0^\circ.5$  and the delta magnitude to 1.35. The software is set up such that these values can be input by the user and varied if desired.)

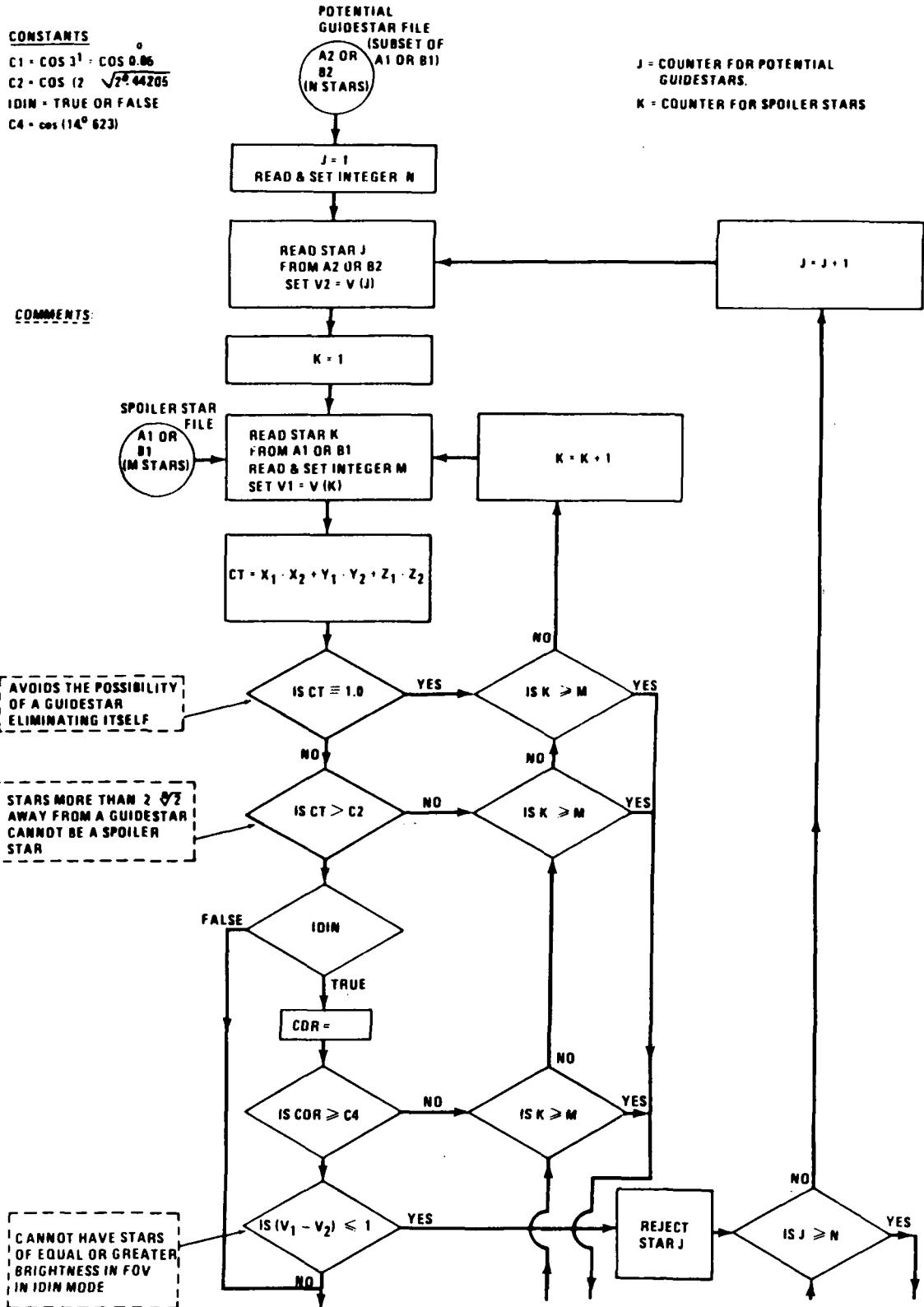


Figure 12. Uniqueness filter for science star 1 (total of L). (Must be applied to potential annulus guidestars in IDOP and IDIN modes and boresight guidestars in IDOP mode.)

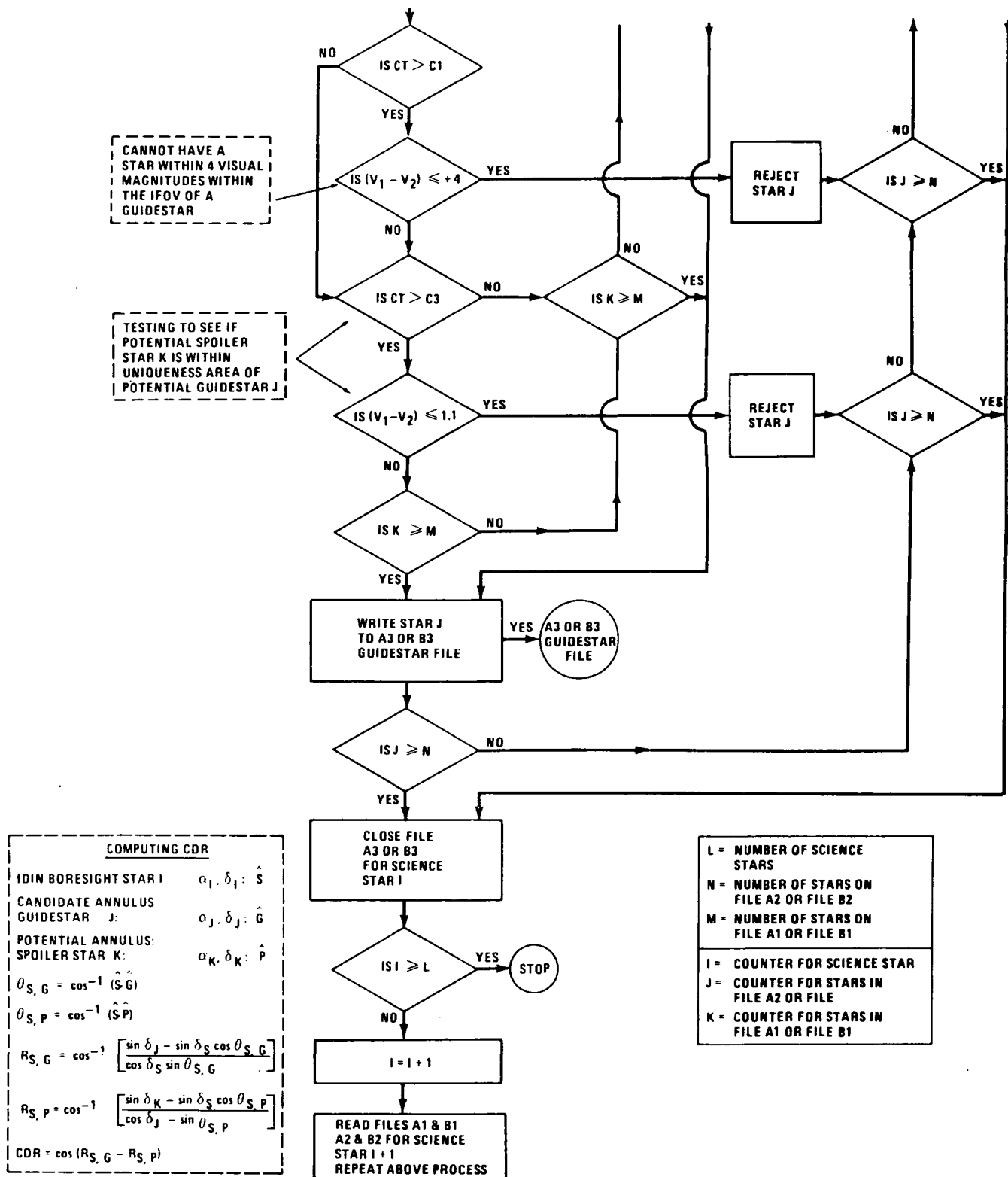


Figure 12. (Concluded)



The same piece of software can be used for the uniqueness filter for both annulus and boresight stars and also for both IDIN and IDOP modes. This filter is shown in flowchart form in Figure 12 and 12A.

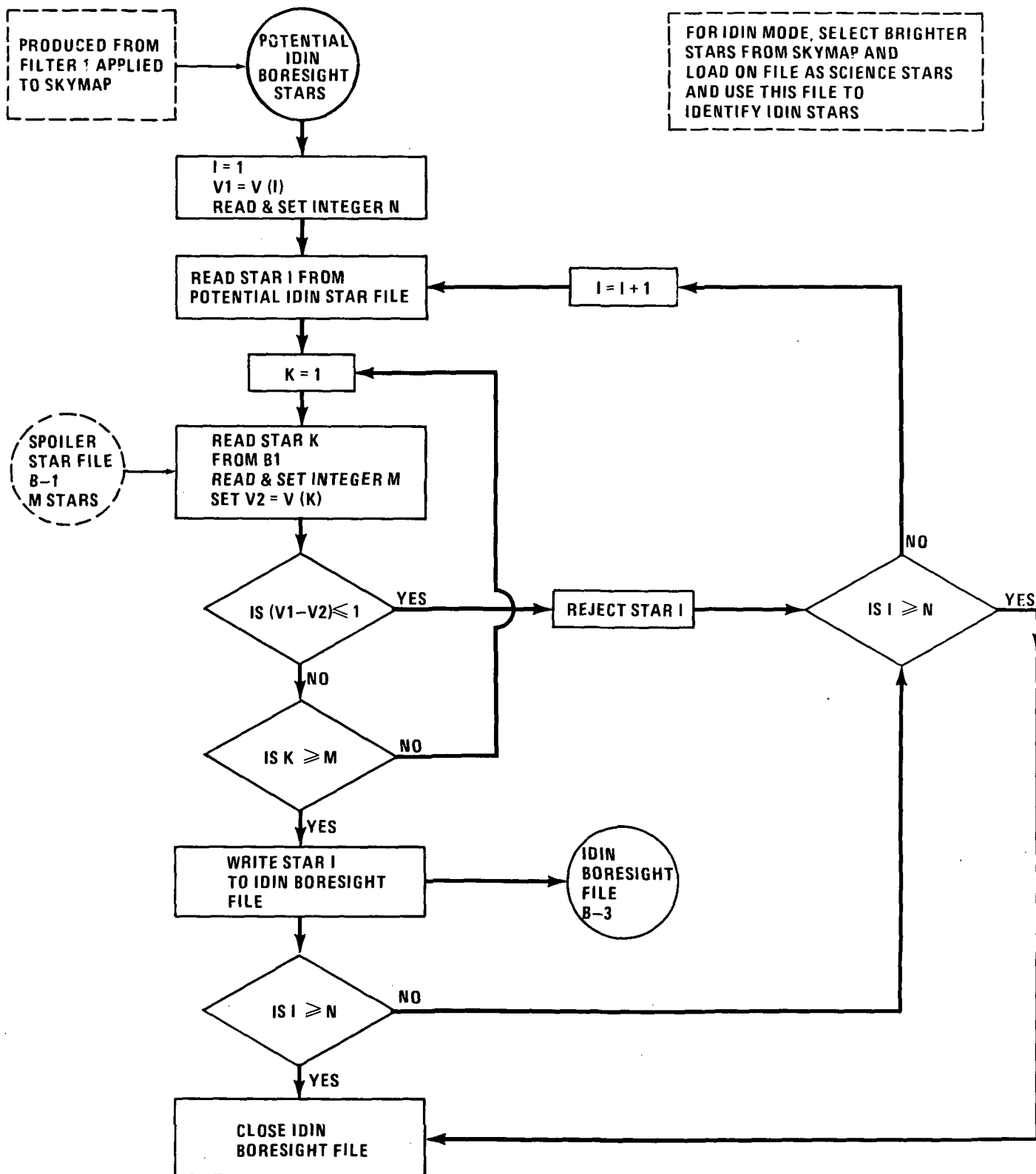


Figure 12A. Uniqueness filter for IDIN boresight guidestars.

## D. Doublets

A doublet is a pair of guidestars used for large error IPS inertial system re-initialization, either one in the boresight tracker and one in a skewed tracker or one in each of the two skewed trackers. If there is a star in the boresight and one in the annulus, then one can always get a doublet with the proper roll angle of the IPS. To get a doublet with one star in each skewed tracker, however, requires a more specialized alignment of the stars to be discussed at length here.

### BST

The FOV of the startracker is approximately a 2 deg x 2 deg square. If the BST is centered on a guidestar then any nearby star, to be guaranteed to be in the FOV regardless of the orientation of the BST FOV, cannot be more than 1 deg away in central angle.

### Skewed Tracker

The dihedral angle formed by the science star in the boresight tracker, a guide star in the center of the FOV of an off-axis tracker, and a nearby star 1 deg in central angle from the guidestar on the edge of the FOV of the off-axis tracker is shown in Figure 13 and can be calculated from spherical trigonometry.

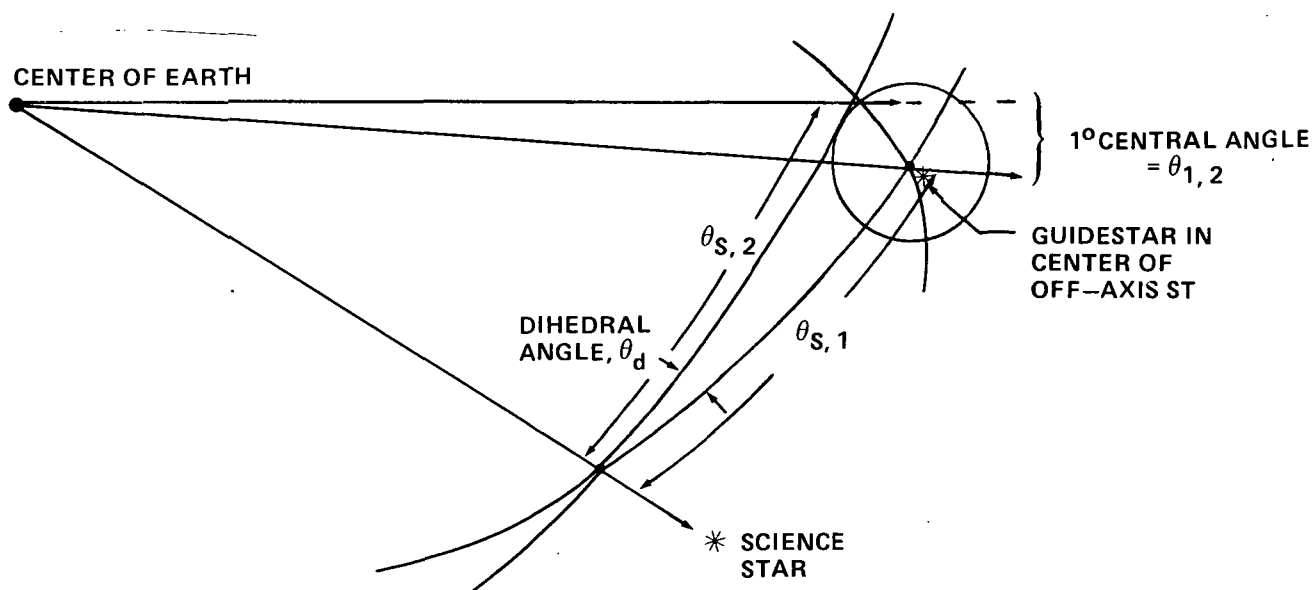


Figure 13. Dihedral angle formed by science star and two off-axis guidestars separated in central angle by 1 deg.

In the diagram let

$\theta_{s,1}$  = central angle between science star and guide star in center of FOV of ST

$\theta_{s,2}$  = central angle between science star and guide star in edge of FOV of ST

$\theta_{1,2}$  = central angle between two guidestars

$\theta_d$  = dihedral angle .

By the law of cosines, the dihedral angle can be calculated to be

$$\theta_d = \cos^{-1} \left[ \frac{\cos \theta_{1,2} - \cos \theta_{s,1} \cos \theta_{s,2}}{\sin \theta_{s,1} \sin \theta_{s,2}} \right] \quad (3)$$

If the central angle between the two off-axis guidestars is held to a constant 1 deg, then the value of the dihedral angle is a function of the angular distance between the BST and the SKT. Figure 14 shows this dihedral angle as a function of the angular separation between the trackers. For the stellar case where this central angle is between 11 and 13 deg, the off-axis guidestars can have a dihedral angle varying between 5°.227 for an 11 deg central angle to 4°.437 for a 13 deg central angle.

To summarize, for a pair of stars in the annulus to serve as a doublet, i.e., one guidestar in each off-axis tracker, the central angle between them must be between 22 and 26 deg and the dihedral angle must be equal to or greater than  $180^\circ - 4^\circ.437 = 175^\circ.563$ , as illustrated in Figure 15.

Figure 16 shows, in flowchart form, the logic for selecting annulus doublets.

### E. Triplets

Some operations require triplets. A triplet is, of course, a star in each of the three star trackers. That is, one in the boresight tracker (BST) and one in each skewed tracker (SKT). The requirements on angular separation in the SKT are the same as those for doublets in the SKTs.

## V. REQUIRED ON-ORBIT CALIBRATIONS

### A. OSP-CAL

A required on-orbit operation is a calibration of the relative position of the three STs relative to each other. This requires a bright star and a dim star in each ST simultaneously (mutual OSP calibration) with all three STs operating in the FT mode. This is called operation F-8 in the ESA/NASA Spacelab Sequences Handbook on page 5-13 [7]. This operation is called OSP-CAL and its requirements are as follows:

- 1) Need a bright star and a dim star in each of 3 trackers.
- 2) Dim star must be dimmer than bright star by >1 Mv.
- 3) Uniqueness criteria for bright star is the same as in IDIN.

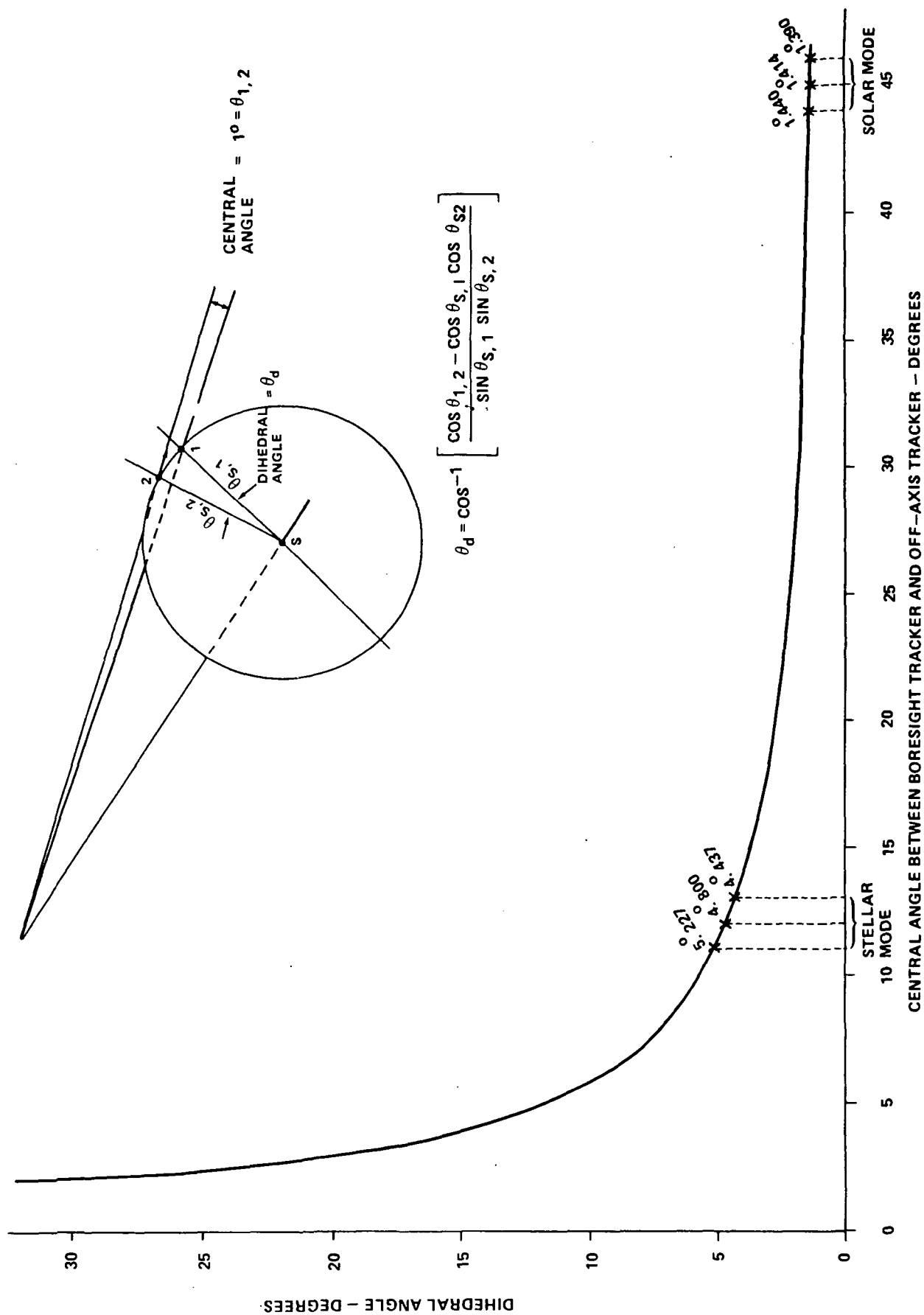


Figure 14. Dihedral angle formed by target star in boresight tracker and two off-axis guide stars (separated by 1 deg central angle) as a function of the angle between the boresight tracker and the off-axis trackers.

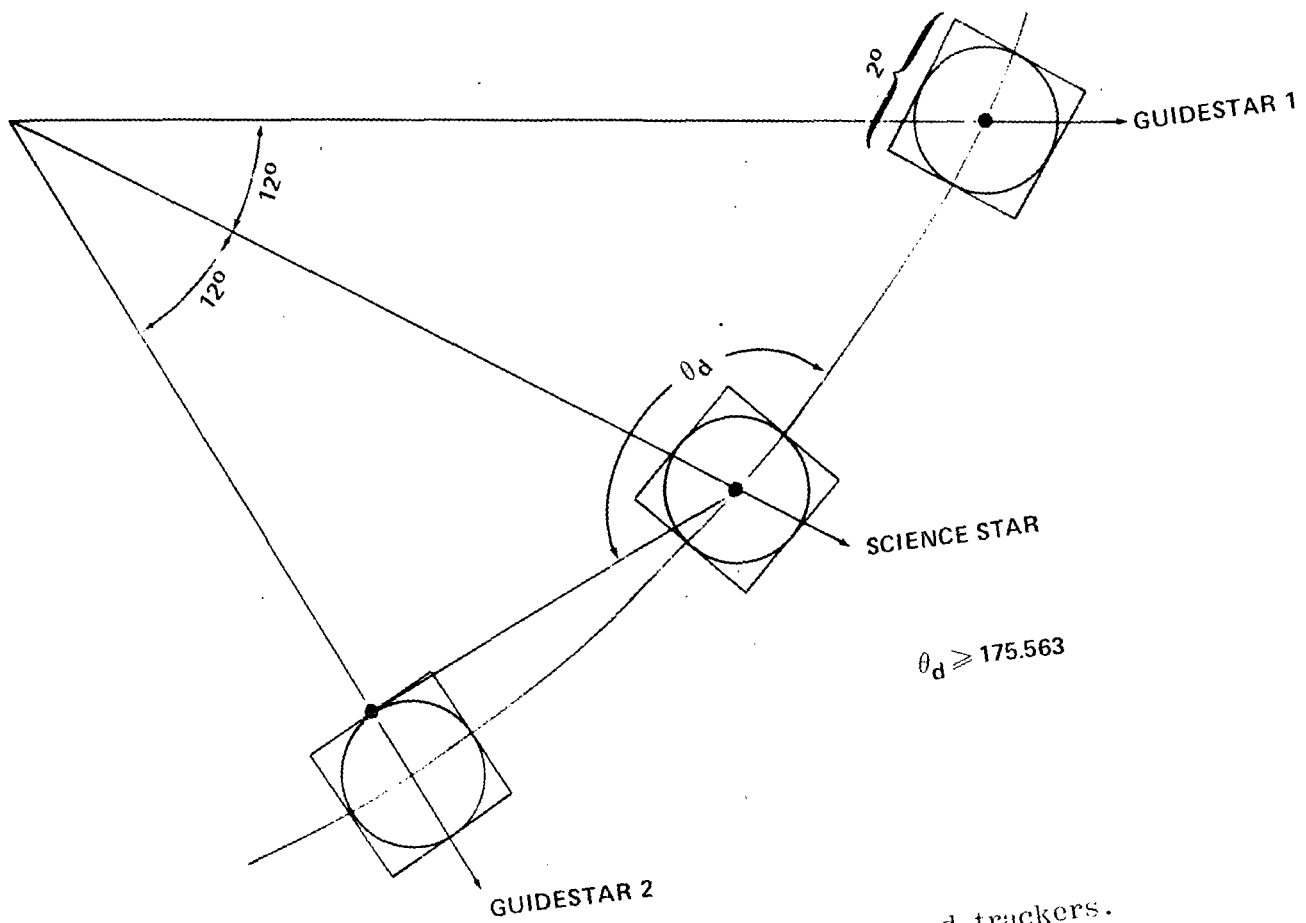


Figure 15. A doublet in the skewed trackers.

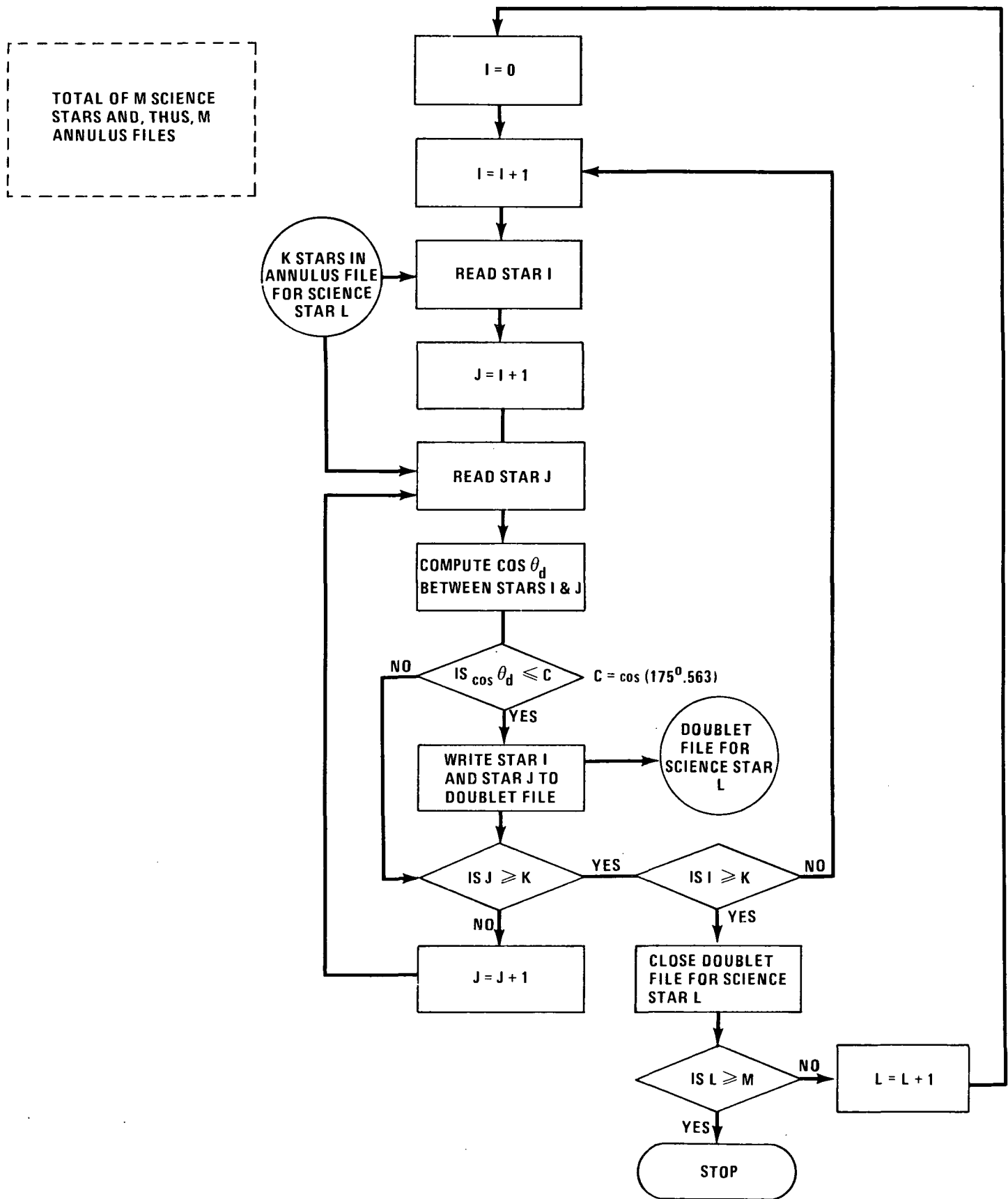


Figure 16. Flowchart for determining annulus doublets.

- 4) Uniqueness area for dim star: no neighbor with magnitude greater than  $M_v(\text{dim}) + 1$  within  $0^\circ.31$  for each tracker.
- 5) Minimum distance between bright and dim star  $\approx 0^\circ.40$ .
- 6) Maximum distance between bright and dim star  $\approx 1^\circ.50$ .
- 7) Recommended not to have either of the two stars in the center of the tracker FOV.
- 8) Recommended that both stars are independent in both "Y" and "Z" such that  $Y_{\text{bright}} \neq Y_{\text{dim}}$ ,  $Z_{\text{bright}} \neq Z_{\text{dim}}$ . Optimum is along diagonals of FHST FOV. (These specs were furnished by Tony Lavoie of EL54 on July 17, 1985.)

## B. GYRO-CAL

The Gyro-Cal is an operation designed to measure the drift rate of the IPS gyros under operating conditions. The requirements are to have two IDIN boresight stars separated by not more than the full-cone slew capability of the IPS gimbal system. In this case, it amounts to separation angles of not more than about 44 deg. It would be desirable to have a pair of triplets formed by the guidestars in the annulus around each IDIN boresight star with each triplet about 90 deg in roll angle from the other. Since this is asking for more than can actually be found, the Gyro-Cal can be performed with doublets with the doublet pairs around each boresight star separated in roll angle by something close to 90 deg.

The Gyro-Cal operation is performed by setting the Orbiter in a fixed attitude with the -Z<sub>o</sub> axis pointing in a direction about half-way between the two IDIN boresight stars. The IPS is to slew over to first one boresight star at a roll angle which will pick up one of the doublets. After the IDOP acquisition is done, the IPS is then to slew over to the second IDIN boresight star with as little change in roll angle as possible to pick up one of the doublets formed by the second star. After this IDOP acquisition is done, the IPS should roll approximately 90 deg to pick up the second doublet about the second IDIN boresight star. After this IDOP acquisition, the IPS should then slew back to the first IDIN boresight star. This represents a total of 4 IDOP acquisitions which should be done in about 50 min with the Orbiter in a stationary position with full K-band coverage if possible. (These requirements were obtained from Bob Smith, Tony Lavoie, and Doug Nixon of EL54 on November 13, 1985.)

The ideal pattern of stars desired for the Gyro-Cal operation is shown schematically in Figure 17.

## VI. EPOCH OF COORDINATES

The coordinates of the stars in the master catalog are listed as right ascension and declination with respect to the epoch 2000.0. The documentation on the IPS from Dornier stated that the coordinates of the guide stars on the objective loads should be true-of-date. Initially, the objective loads were written this way. Later, however, it was requested that the coordinates on the objective loads be changed to Mean-of-1950

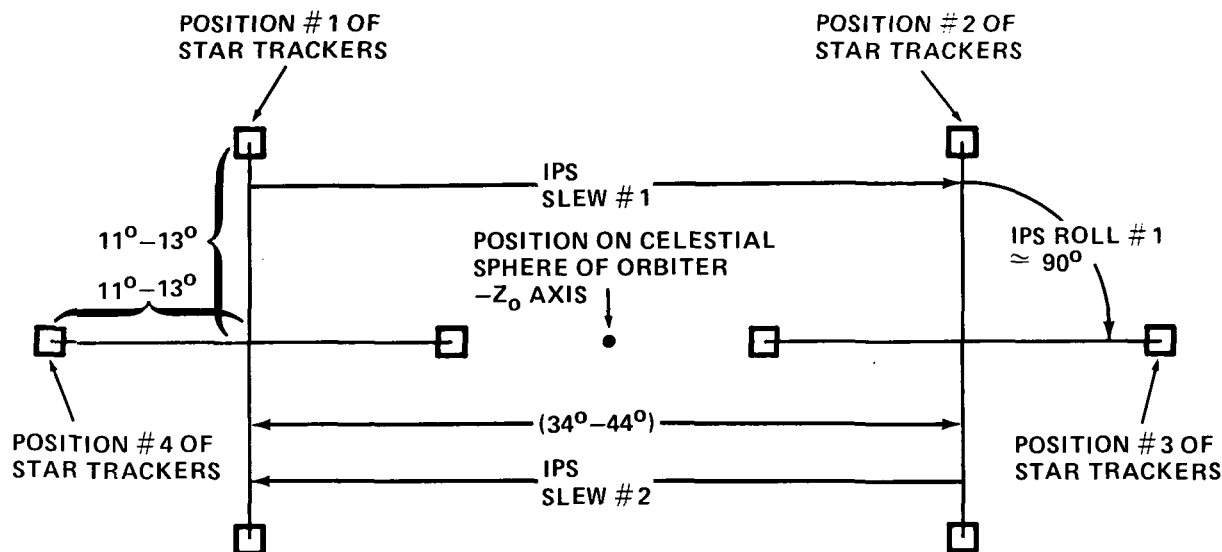


Figure 17. Schematic of ideal set of orientations for IPS to do Gyro-Cal operation.

to be compatible with the PI's joint target file and also with the system in which the Orbiter operates. The objective loads were changed to this system in late November of 1985. There is the capability in the program, however, for a user to choose a different epoch if that should ever be necessary.

## VII. DETERMINATION OF GUIDESTARS IN FOV OF STAR TRACKERS

In order to calculate objective loads, one must know what stars are in the FOV of each star tracker; the left and right skewed trackers and the boresight tracker. In order to know this, one must know at what science star the boresight tracker is pointed and then the position angle of the skewed trackers with respect to the meridian plane through the North pole, i.e., the orientation as depicted by Figure 7.

The science star at which the boresight tracker is pointed is established by the schedule or timeline for the mission. The guidestars available for each science star in the boresight and annulus regions are contained on the files B3 and A3, respectively, as described in section IV and illustrated in Figure 9. The position angle that the OSP has is either fixed by PI requirement or can be chosen by the mission planner. If the mission planner has the freedom to choose this position angle, he needs some criteria to guide him in making that choice. One obvious criteria is that he choose the roll angle to put the best guidestars in the FOV of the skewed trackers. What constitutes "best" may be somewhat subjective.

A criterion established late in the fall of 1985 for selecting position angles, in those cases where the PI had not specified a position angle, was to select one which would minimize the IPS gimbal roll angle both from the preceding pointing and to the next pointing. The reason for doing this was two-fold: one was to reduce the time required to get the IPS in the proper position, but the more important one was to minimize the gyro drift incurred in making the maneuver by minimizing the maneuver which the IPS had to do. Minimizing the gimbal roll requires an Orbiter attitude



timeline (P, Y, R versus time) so that the IPS gimbal angles can be calculated for various celestial position angles. This is done with a program called GIMOP (for GIMbal Angle Optimization Program). It is described in some detail in Section IX.

The first objective of this section is to establish means by which software can be set up to determine what guidestars are in the FOV of each tracker for given position angles. These position angles will not be chosen at random but will be chosen to ensure that at least one star is in the FOV of one skewed tracker. Calculations will then be made to determine if there are any other guidestars in the FOV of each of the three trackers.

The first thing to be done is to establish the equations to make the calculations required to determine if a star is in the FOV of a star tracker given that the boresight is pointed to a certain place on the celestial sphere and that the position angle has a certain value.

The FOV of each tracker is approximately a  $2^\circ.2 \times 2^\circ.2$  square and any point on it is referenced by the geometric coordinates ( $Y_G, Z_G$ ) each of which can vary between the limits  $-1.^\circ1 \leq Y_G, Z_G \leq +1.^\circ1$ , depending upon the particular model flown. These coordinates are parallel to the M coordinates illustrated in Figure 1.14-1 of Reference 8.

What is necessary is to be able to map any pair of inertial coordinates ( $\alpha, \delta$ ) into the ( $Y_M, Z_M$ ) coordinates of the approximately  $2^\circ.2 \times 2^\circ.2$  FOV.

#### A. The Boresight Tracker (BST)

The boresight star tracker (BST) of the OSP is aligned with the IPS platform system and is considered to be coincident with the E1 system as explained in paragraph 1.16 of Reference 8. Other experiments mounted on the IPS such as HUT or WUPPE may or may not be coincident with the BST. In general, they are not exactly coincident. They are offset by some small angles in pitch, yaw, and roll (P, Y, R). By definition, the transformation matrix to rotate the coordinate system from the experiment position (say HUT) to the platform position (BST) is given by

$$T_{P,E} = (R)_X (Y)_Z (P)_Y \quad (4)$$

where the offset angles P, Y, and R must be determined from alignment measurements at KSC after installation of the OSP and the instruments on the IPS. These angles for the HUT relative to the BST on ASTRO-1 are

$$P \cong -0.^\circ 032350$$

$$Y \cong +0.^\circ 066919$$

$$R \cong -0.^\circ 496100$$

Further details on determining these angles and the  $T_{P,E}$  matrix are contained in Appendix A.

If the science target is at a right ascension and declination of  $(\alpha_s, \delta_s)$ , then the coordinate rotation to get from the "zero" or reference inertial coordinate position to one which points the X-axis at the science target is  $(-\delta_s)_Y (\alpha_s)_Z$ . This can be visualized from an examination of Figure 7 or Figure 8. After these rotations, a further roll about the X-axis will not change the inertial pointing direction of the X-axis; so, in general, the coordinate transformation to get from the inertial system to wherever the experiment system (Ei) is pointing is given by the matrix

$$T_{E,0'} = (\text{Roll})_X (-\delta_s)_Y (\alpha_s)_Z \quad (5)$$

This matrix is also given in paragraph 3.12 of Reference 8. The way that roll is determined in individual cases will be explained shortly when the skewed trackers are discussed. In general, though, the roll is either specified by the PI for scientific reasons or is specified in order to point one of the skewed trackers at some desired guide star.

We combine equations (4) and (5) to get the total transformation from the inertial coordinate system to the platform system as

$$T_{0,0'} = T_{P,E} * T_{E,0'} \quad (6)$$

which is also given in paragraph 3.15 of Reference 8. Any vector expressed in the inertial system can be expressed in the platform system (S1) by multiplying it by the matrix defined in equation (6). This matrix, defined by equation (6), is the one which goes on the objective loads, as will be discussed in Section VIII. The square FOVs of the star trackers are mounted square with respect to the baseplate or square with respect to the M-system. This system is rotated 45 deg about the x-axis from the S-system as is illustrated in Figure 1.14-1 of Reference 8. Thus, to get from the S-system to the M-system one must multiply the matrix defined by equation (6) by the matrix  $(-45^\circ)_X$  as is shown in paragraph 3.8 of Reference 8. Thus, the total transformation to get from the inertial system to the M1 system is given by

$$T_{M1,I} = (-45^\circ)_X T_{P,E} * T_{E,0'} \quad (7)$$

Any inertial vector can be transformed to the M1 system by multiplying it by the matrix defined by equation (7); i.e., if  $GS_I$  is a unit vector to a star in the inertial system, then a unit vector to the star expressed in the M1 system is

$$GS_{M1} = T_{M1,I} GS_I \quad (8)$$

If this unit vector has components in the M1 system of  $X_{GSM1}$ ,  $Y_{GSM1}$ ,  $Z_{GSM1}$ , then the FOV components are:

$$Y_{M1} = \tan^{-1} (Y_{GSM1}/X_{GSM1})$$

$$Z_{M1} = \tan^{-1} (Z_{GSM1}/X_{GSM1})$$

If  $\ell_b$  is the total length of the boresight tracker FOV ( $2^\circ.2$ ) and  $W_b$  is the total width of the boresight tracker FOV (again  $2^\circ.2$ ) then the star whose coordinates are given by equation (8) will be in the BST FOV if

$$|Y_{M1}| \leq \ell_b/2 \quad \text{and} \quad |Z_{M1}| \leq w_b/2 \quad .$$

The roll angle which goes into the  $T_{E,0}$  matrix defined by equation (5) is determined as follows: The orientation of the skewed trackers on the celestial sphere in the "zero-roll" position is as shown in Figure 18. As measured from the local meridian plane, the roll angle of the RST is 135 deg.

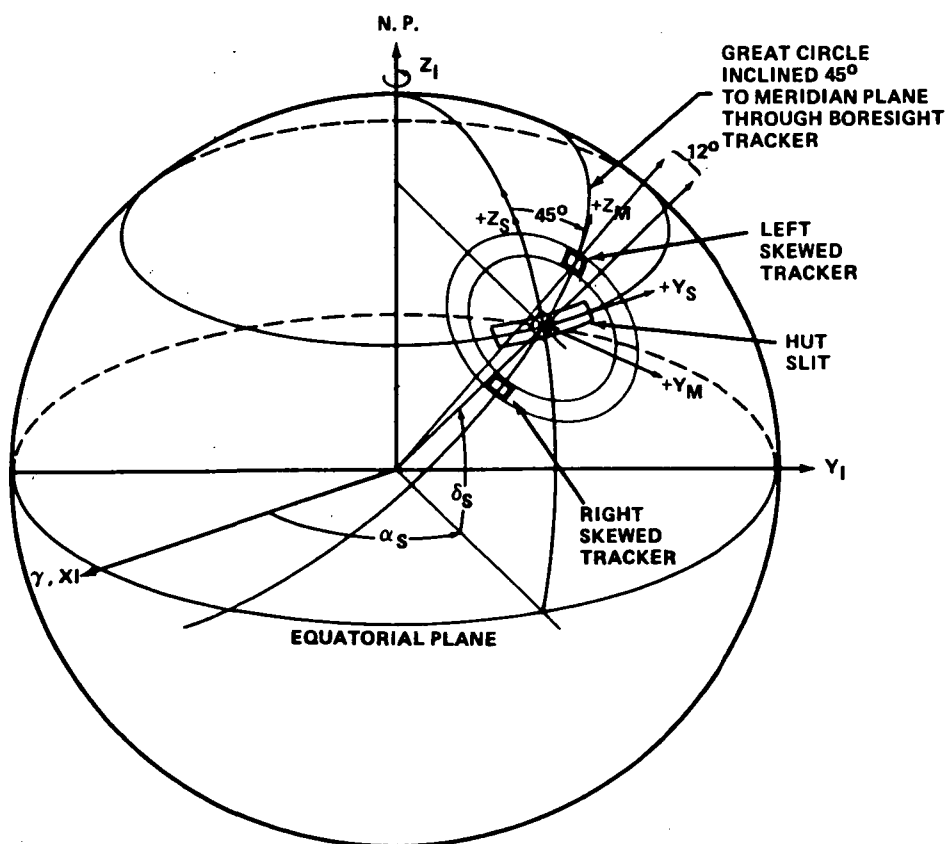


Figure 18. Orientation of OSP in "zero-roll" position when pointing to a science star on the celestial sphere.

To set the roll of the RST back to zero, it would have to execute a -135 deg roll about the x-axis. If there is then some guide star in the annulus shown in Figure 18 with a position angle PA and it was desired to put it in the FOV of the RST, one would have to give the RST a further roll of  $360^\circ - PA$ ; therefore, the total roll angle of the IPS required to place a guide star with position angle PA into the FOV of the RST is

$$\text{Roll} = -135^\circ + (360^\circ - PA) \quad . \quad (10)$$

This is the roll angle that goes into equation (5) and onto the objective loads which will be defined in Section VIII.

#### B. The Left Skewed Tracker (LST) and the Right Skewed Tracker (RST)

The S and M systems for the RST on the IPS are labeled S2 and M2 and those for the LST are labeled S3 and M3 (see Figure 1.14-1 in Section 1.14 or the figure in Section 3.8 of Reference 8). The transformation required to rotate from the S1 (BST) system to the S2 (RST) system as outlined in Section 3.9 of Reference 8 is

$$\begin{aligned} T_{S2,S1} &= (-45^\circ)_x (-\alpha_R)_z (+45^\circ)_x \quad (11) \\ &= 1/2 \begin{pmatrix} 2 \cos \alpha_R & -\sqrt{2} \sin \alpha_R & -\sqrt{2} \sin \alpha_R \\ \sqrt{2} \sin \alpha_R & 1 + \cos \alpha_R & -1 + \cos \alpha_R \\ \sqrt{2} \sin \alpha_R & -1 + \cos \alpha_R & 1 + \cos \alpha_R \end{pmatrix} \end{aligned}$$

where  $\alpha_R$  is the skew angle between the center lines of the BST and the RST. For the stellar mode,  $\alpha_R$  is nominally 12 deg but exact alignment measurements will yield a slightly different value. A picture of this transformation is shown in Figure 3.9-1 of Reference 8.

The total transformation to go from the inertial system to the M2 system is given by

$$T_{M2,I} = (-45^\circ)_x (RA_R)_x T_{S2,S1} T_{P,E} T_{E,0'} \quad . \quad (12)$$

The matrix  $(RA_R)_x$  is a slight rotation angle about the x-axis of the RST to account for any slight misalignments from an "exact square" mounting with respect to the base plate (as pictured in Section 3.8 of Reference 8). Again, this can only be determined from alignment measurements at KSC after OSP is mounted on the IPS. Its exact value will vary from mission to mission.

Any guidestar vector expressed in inertial coordinates  $\hat{GS}_I$  can be transformed to the M2 system by the equation

$$\hat{GS}_{M2} = T_{M2,I} \hat{GS}_I \quad (13)$$

The FOV components are then

$$\begin{aligned} Y_{M2} &= \tan^{-1} (Y_{GSM2}/X_{GSM2}) \\ Z_{M2} &= \tan^{-1} (Z_{GSM2}/X_{GSM2}) \end{aligned} \quad (14)$$

If  $\ell_R$  is the length of the RST FOV and  $W_R$  is the width of the RST FOV, then the star whose coordinates are calculated by equations (13) and (14) will be in the RST FOV if

$$|Y_{M2}| \leq \ell_R/2 \quad \text{and} \quad |Z_{M2}| \leq W_R/2$$

The dihedral angle formed by the BST and the two skewed trackers is nominally 180 deg as illustrated by Figure 6. Due to manufacturing tolerances, misalignments during mounting and other possible factors, however, the true dihedral angle will not be exactly 180 deg. If, as determined from alignment measurements, the deviation of the dihedral angle from 180 deg is  $\epsilon$  ( $\epsilon > 0$  for dihedral angle  $> 180$  deg and  $\epsilon < 0$  for dihedral angle  $< 180$  deg) then the transformation matrix from the BST S1 system to the LST S3 system is given by

$$T_{S3,S1} = (-45^\circ - \epsilon)_X (+\alpha_L)_Z (45^\circ + \epsilon)_X \quad (15)$$

where  $\alpha_L$  is the skew angle between the center lines of the BST and LST. For the stellar mode,  $\alpha_L$  is nominally 12 deg but exact alignment measurements will yield a slightly different value. A picture of the transformation is shown in Figure 3.9-1 of Reference 8.

The total transformation from the inertial system to the M3 system is then

$$T_{M3,I} = (-45^\circ)_X (RA_L)_X T_{S3,S1} T_{P,E} T_{E,0} \quad (16)$$

again where  $(RA_L)_X$  accounts for slight misalignments of the LST from an "exact square" mounting with respect to the base plate.

Any guide star vector expressed in inertial coordinates  $\hat{GS}_I$  can be transferred to the M3 system by the equation

$$\hat{GS}_{M3} = T_{M3,I} \hat{GS}_I \quad (17)$$

The FOV coordinates are then

$$\begin{aligned} Y_{M3} &= \tan^{-1} (Y_{GSM3}/X_{GSM3}) \\ Z_{M3} &= \tan^{-1} (Z_{GSM3}/X_{GSM3}) \end{aligned} \quad (18)$$

If  $\ell_L$  is the length of the LST FOV and  $W_L$  is the width of the LST FOV, then the star whose coordinates are calculated by equations (17) and (18) will be in the LST FOV if

$$|Y_{M3}| < \ell_L/2 \quad \text{and} \quad |Z_{M3}| < W_L/2$$

In practice, every star in the entire annulus as pictured in Figure 7 will not be checked to see if it is in the FOV of the RST by equations (13) and (14) or in the FOV of the LST by equations (17) and (18). In practice, when the coordinates of the science star are read from the COO file, a desired roll angle will also be read with it. This is a desired roll angle of the HUT spectrographic slit and it will cause the skewed trackers to have certain positions (roll angles) in the annulus. Only those stars whose roll angles are within about  $\pm 8$  deg of the skewed tracker positions will be checked to see if they are in the FOVs of those trackers.

### C. Roll Angle and the HUT Spectrographic Slit

When the IPS is in the cradle position in the orbiter, the HUT slit is parallel to the orbiter wing plane or parallel to the orbiter y-axis. The IPS S-system is also parallel to the orbiter Y-axis in this position, although positive is in the opposite direction to that of the orbiter y-axis as shown in Figure 1A. With the s-system aligned with the standard inertial system and even with yaw and pitch maneuvers from that position as shown in Figure 18, the HUT slit would be aligned perpendicularly to the local meridian plane. The end of the slit toward the +Ys axis would have a position angle of 90 deg (roll angle of 270 deg). The roll angle of the RST in the "zero-position," as shown in Figure 18, is +135 deg so the difference in the roll angles of the +Ys axis of the HUT slit and the RST is 270 deg - 135 deg = 135 deg. When one sees a "roll angle" on the MTL file, this is really the desired position angle of the +Ys axis of the HUT slit. The P.A. of the RST is then 135 deg greater than that of the HUT slit. As an example, on target 4410-100 the desired "roll angle" (position angle) is listed as 18 deg. This means that the P.A. of the RST would be 135 deg + 18 deg = 153 deg, and the objective load roll angle would be, according to equation (10), Roll = -135 deg + (360 deg - 153 deg) = 72 deg.

Thus, the P.A. of the RST would be 153 deg so one would look only at stars with position angles of 153 deg  $\pm$  8 deg to determine those that might be in the FOV of the RST and look only at stars with position angles of 333 deg  $\pm$  8 deg to determine those which may be in the FOV of the LST.

To determine which stars are actually in the FOV of the boresight and skewed trackers, one must know their sizes and mounting misalignments as determined by measurements or calibrations. The quantities which must be known are shown in Figure 19. Some preliminary quantities which must be calculated from these values are shown in Figure 20. These include the misalignment matrix  $T_{P,E}$  and some other transformation matrices which are dependent on the star tracker alignments but independent of where the IPS is pointed. A flow chart for determining which stars are in the FOV of each of the three star trackers is shown in Figure 21. Figure 22 shows how the count rate for a given guide star of given spectral class and position in the FOV of a given tracker is determined. Further details about determining the count rates are given in Appendix B.

<p><u>INPUT:</u></p> <p><u>I. BORESIGHT TRACKER CHARACTERISTICS:</u></p> <p>LENGTH: <math>\ell_b</math> (DEGREES)          WIDTH: <math>w_b</math> (DEGREES)          MISALIGNMENT ANGLES: P, Y, R (DEGREES)          (OR)          MISALIGNMENT MATRIX: <math>T_{P,E}</math>          INSTRUMENT IN BORESIGHT POSITION: <math>FM_B</math></p> <p><u>II. RIGHT SKEWED TRACKER CHARACTERISTICS:</u></p> <p>LENGTH: <math>\ell_R</math> (DEGREES)          WIDTH: <math>w_R</math> (DEGREES)          RIGHT SKEW ANGLE: <math>\alpha_R</math> (DEGREES)          ROTATION OF RIGHT TRACKER: <math>RA_R</math> (DEGREES)          (FROM 'SQUARE' MOUNT)          INSTRUMENT IN RIGHT SKEWED POSITION: <math>FM_R</math></p> <p><u>III. LEFT SKEWED TRACKER CHARACTERISTICS:</u></p> <p>LENGTH: <math>\ell_L</math> (DEGREES)          WIDTH: <math>w_L</math> (DEGREES)          LEFT SKEW ANGLE: <math>\alpha_L</math> (DEGREES)          ROTATION OF LEFT TRACKER: <math>RA_L</math> (DEGREES)</p> <p>DEVIATION OF DIHEDRAL ANGLE FROM 180°: <math>\epsilon</math> (DEGREES)          INSTRUMENT IN LEFT SKEWED POSITION: <math>FM_L</math></p>
--

Figure 19. Sizes and mounting characteristics of trackers which must be known for accurate determination of stars in their FOVs.

COMPUTE:

1. IF MISALIGNMENT ANGLES P, Y, R ARE INPUT

$$T_{P,E} = (R)_X (Y)_Z (P)_Y$$

IF  $T_{P,E}$  MATRIX IS INPUT, COMPUTE MISALIGNMENT ANGLES

$$P = \tan^{-1} [-T_{13}, T_{11}]$$

$$R = \tan^{-1} [-T_{32}, T_{22}]$$

$$Y = \tan^{-1} [T_{12}, (T_{11} * \cos P - T_{13} * \sin P)]$$

2.  $T_{S2,S1} = (-45^\circ)_X (-\alpha_R)_Z (+45^\circ)_X$

$$T_{INT,R} = (-45^\circ)_X (R)_X T_{S2,S1} \cdot T_{P,E}$$

$$T_{S3,S1} = (-45^\circ - \epsilon)_X (+\alpha_L)_Z (45^\circ + \epsilon)_X$$

$$T_{INT,L} = (-45^\circ)_X (R)_X T_{S3,S1} \cdot T_{P,E}$$

Figure 20. Preliminary calculations to be done from mounting characteristics before determining guidestars in FOVs of star trackers.



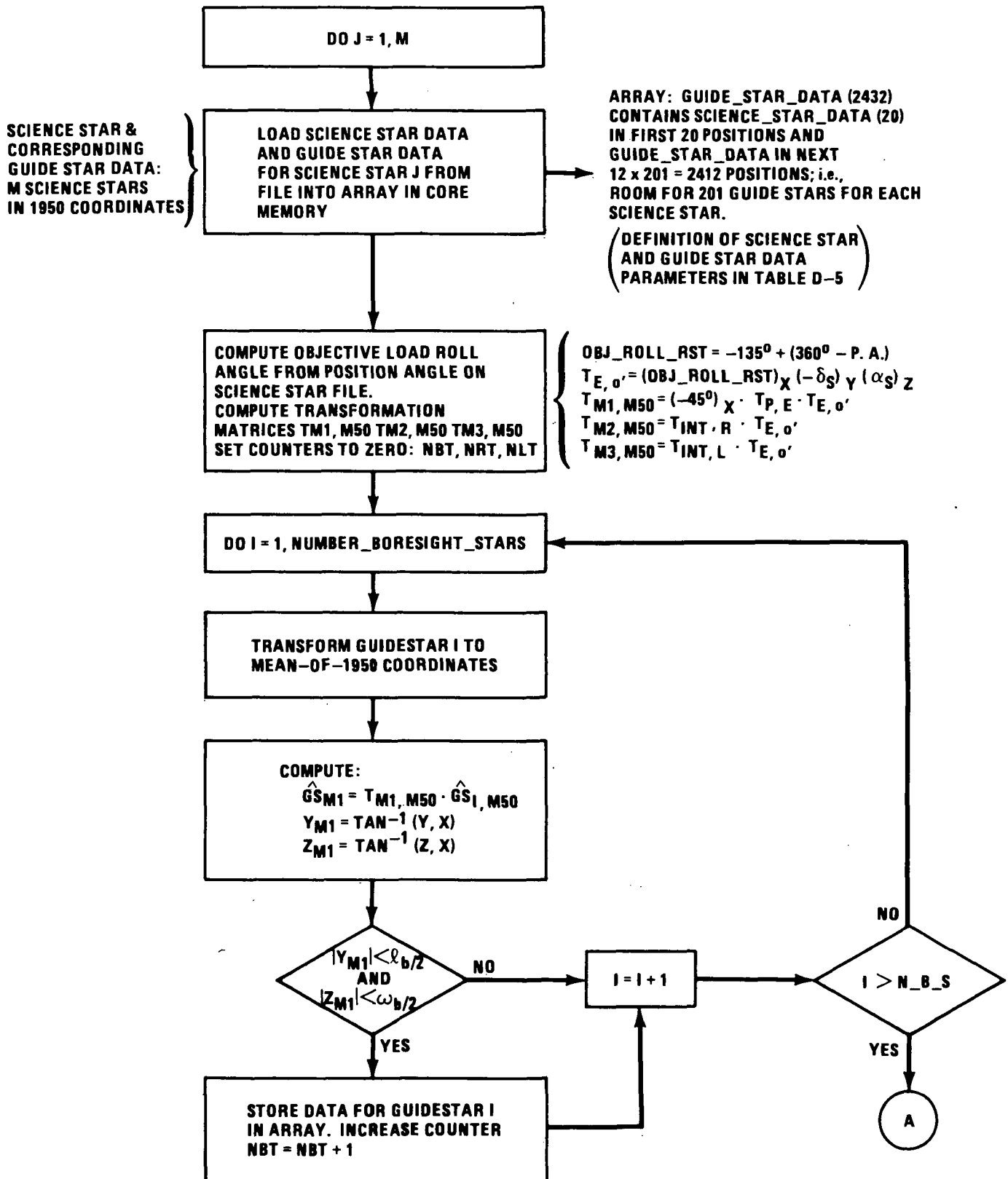


Figure 21. Flow chart for determining which stars are in FOV of each of the star trackers when pointing at science star J with given roll angle.

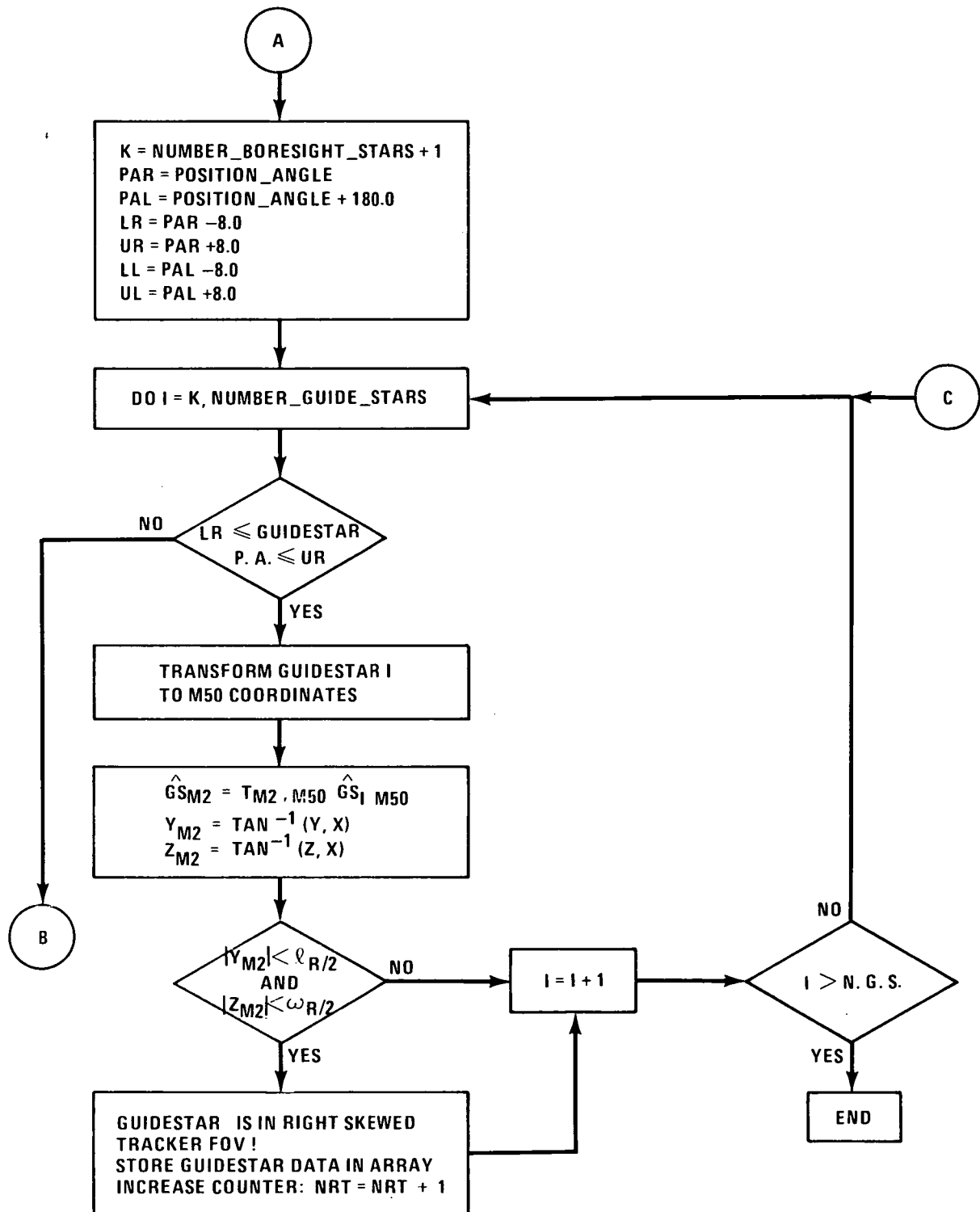


Figure 21. (Continued)

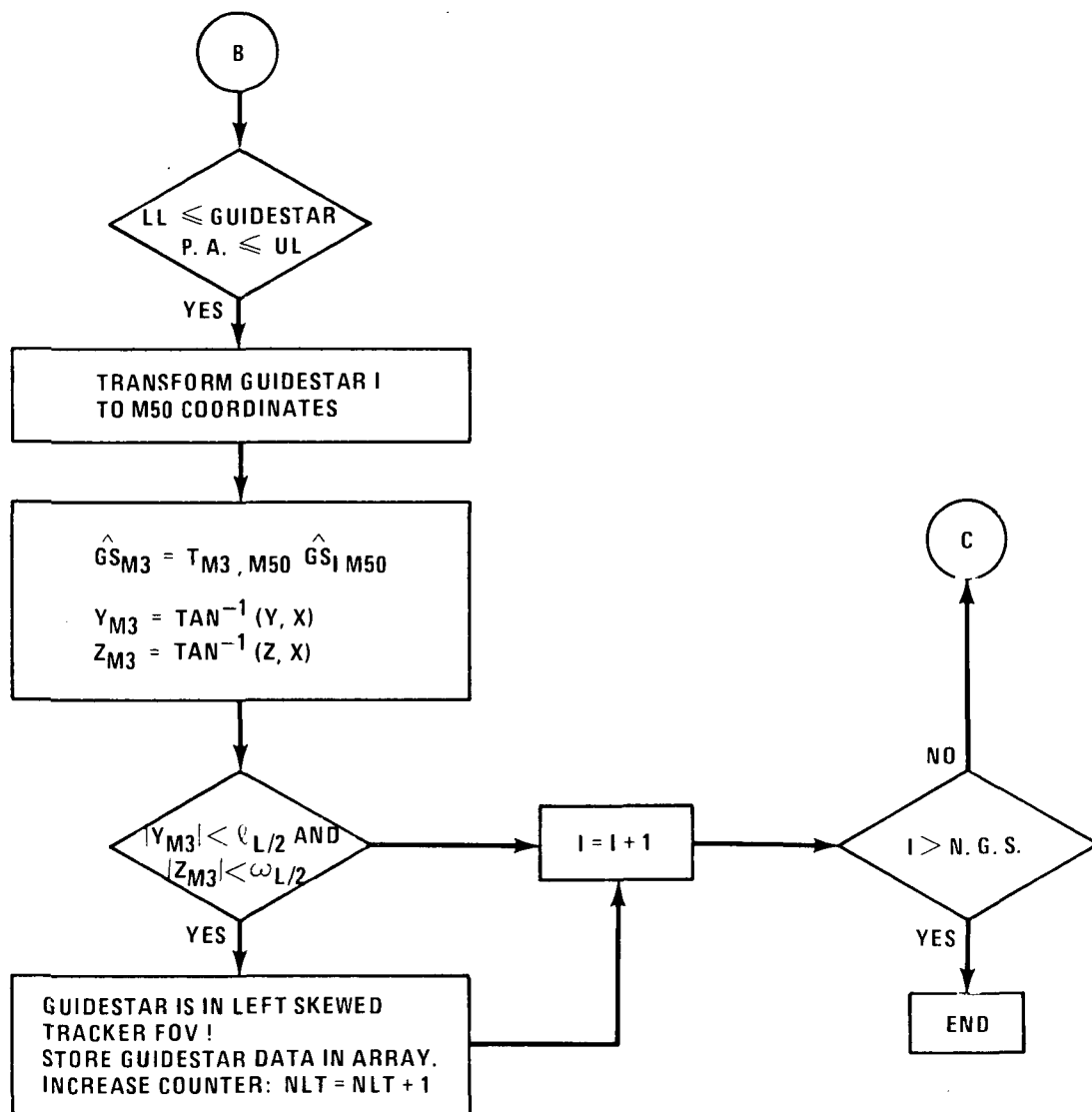


Figure 21. (Concluded)

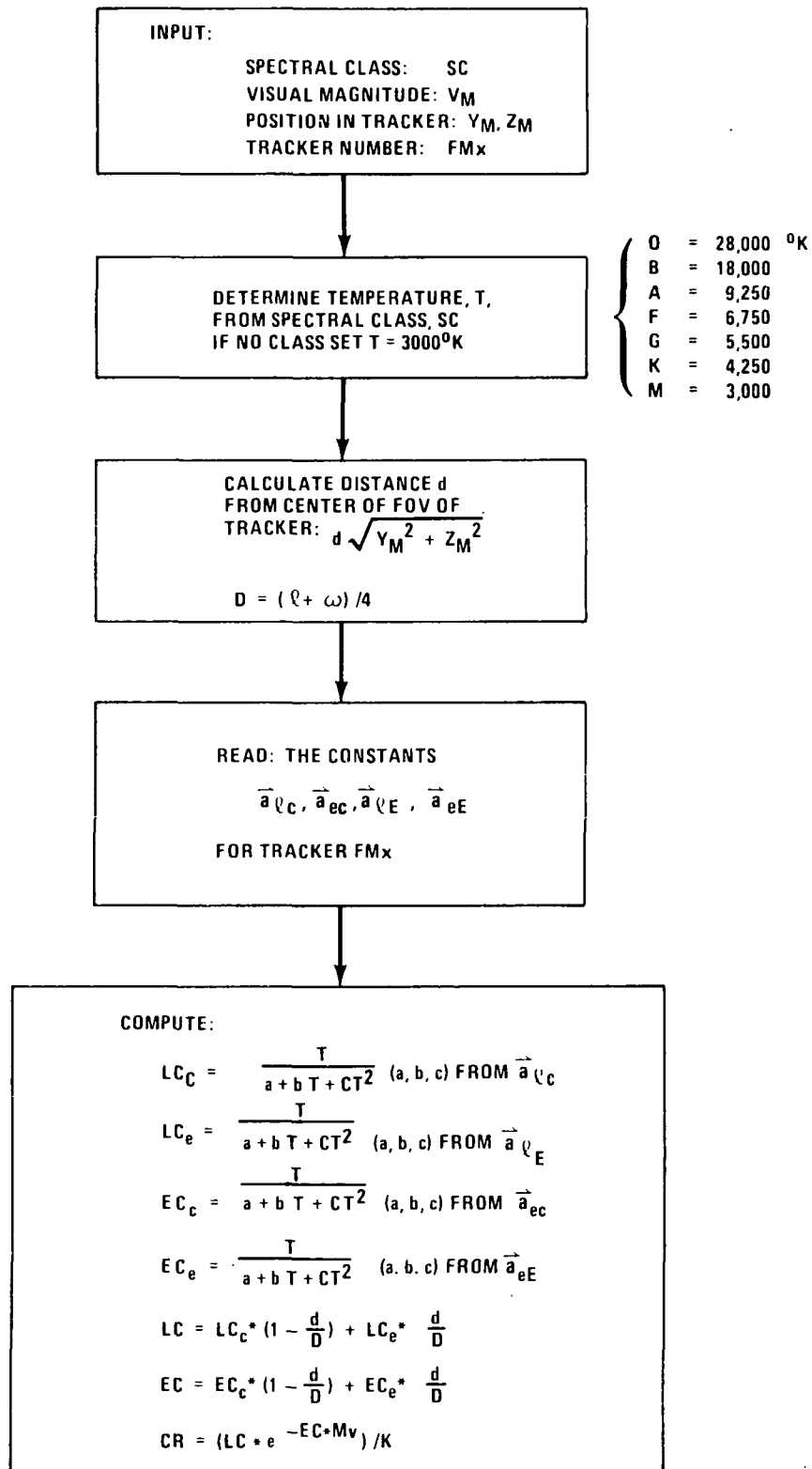


Figure 22. Determination of count rates for stars of spectral class SC and visual magnitude  $V_M$  appearing in the FOV of a star tracker.

## VIII. OBJECTIVE LOADS

After roll angles and guidestars have been selected for each science operation there still remains the task of writing objective loads to be placed on the Spacelab computer MMU. The objective load, in essence, tells the IPS which direction to point and where to look for the guidestar and how bright it should be. The definition of the objective load as provided by Tony Lavoie of EL54 is given in Table VIII-1.

Most of the variables there are self-explanatory but a few may need further elaboration. The experiment number in element 9 will always be 1 for the IPS for guidestar alignment, i.e., IDIN mode. It will be 2 for the HUT in the IDOP mode. The direction cosine matrix (DCM) in element 24 is defined in paragraph 3.15 of Reference 8 as

$$T_{O,O'} = T_{P,E} \cdot T_{E,O'} \quad (19)$$

where from paragraph 3.12 of Reference 8,

$$T_{E,O'} = (\text{Roll})_X (-\delta)_Y (\alpha)_Z \quad (20)$$

and for the IPS,

$$T_{P,E} = I \quad (21)$$

$$T_{O,O'} = T_{P,E} (\text{Roll})_X (-\delta)_Y (\alpha)_Z \quad (22)$$

For experiments other than the IPS,  $T_{P,E}$  will differ from the identity matrix. The  $\alpha$  and  $\delta$  in equation (20) or equation (22) is that of the science target not the guidestar. The roll angle is a function of the guidestar being used. The position angles for the guidestars are calculated as in equation (1). The roll angle that goes on the MMU, however, is not the same as that calculated from equation (1). If we call that angle (1) the position angle, then the roll angle that goes on the MMU for the Right Star Tracker is:

$$\text{Roll}_{\text{RST}} = -135^\circ + (360^\circ - \text{P.A.}_{\text{RST}}) \quad (23)$$

and for the LST

$$\text{Roll}_{\text{LST}} = +45^\circ + (360^\circ - \text{P.A.}_{\text{RST}}) \quad (24)$$

Figure 18 makes it clear why these values are correct.

Elements 28 through 36 are fairly straight-forward, but to make them even clearer, they are laid out in detail in Table VIII-2. Note that there are three modes here, IDIN, IDOP, and OSP CAL, and these elements are slightly different for the three different modes. The GYRO CAL is treated as a special case of the IDOP loads. Stars which satisfy the IDIN criteria are used but they are loaded as IDOP loads and the same star is put on the load twice for redundancy.

The count rates caused by a star of magnitude  $M_v$  appearing in the FOV of a star tracker is given by the equation

$$CR = (LC * e^{-EC * M_v}) / K \quad (25)$$

where the leading "constant," LC, and the exponential "constant," EC, are not constants but functions of the temperature (spectral class) of the star being observed, its position in the FOV of the tracker and the particular instrument (FM1-FM6) being used. Appendix B gives details on the determination of these "constants." K is called the detection threshold constant with a current value of 2.55.

The Y and Z positions in the trackers in the OSP CAL mode represent the positions in the tracker M-system as shown in paragraph 1.15 of Reference 8.

The  $T_{P,E}$  matrix as used in equation (22) is the identity matrix for the IPS (exp. 1) as shown in equation (21). For the HUT (exp. 2), the  $T_{P,E}$  matrix as determined from ground measurements at KSC and calculations as shown in Appendix A is:

$$T_{P,E}^{(2)} = \begin{pmatrix} 0.99999916 & +0.001167956 & +0.0005646101 \\ -0.001163024 & +0.99996183 & -0.0086591300 \\ -0.000574702 & +0.00865846 & +0.99996235 \end{pmatrix} \quad (26)$$

Tables VIII-3, VIII-4, and VIII-5 give examples of IDIN, IDOP, and OSP CAL loads, respectively. The computer program which generates this data is called OBJUP.

TABLE VIII-1. MDP OBJECT FILE PARAMETER DEFINITION

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
1	ST_MODE	Integer	<u>Stellar Mode Indicator.</u> For Stellar Mode, this should always be set to "1". For Solar or Earth mode, the value should be "0".
2	ST_IDOP_IDIN	Integer	<u>IDOP Mode Indicator</u> (used in Stellar Mode only). If objective is an IDOP function, which means that IPS is in the operational mode, the value should be set to "1". If not, the value should be "0". This corresponds to IDIN, which is the initial mode of operation, and also contains OSP calibration mode.
3	SO_MODE	Integer	<u>Solar Mode Indicator.</u> For Solar mode, the value is "1". For Stellar and Earth Modes; the value is "0".
4	SO_ROLCTR_LOS	Integer	<u>Roll type identifier for Solar Mode.</u> A "1" indicates a roll about the sun center, whereas a "0" indicates a roll about the current LOS. For Stellar and Earth Modes, this should be set to "0".
5	EA_MODE	Integer	<u>Earth Mode Indicator.</u> For Earth Mode, this should be set to "1". For Stellar and Solar Modes, this should be set to "0".
6	EA_LMLVM	Integer	<u>Earth Landmark Track Identifier.</u> This parameter is used only in Earth Mode to indicate either a Landmark Track objective (use a value of "1") or a Local Vertical objective (a value of "0"). For Stellar and Solar Modes, this should be set to "0".
7	FILLER_1	Array (1)	<u>Dummy Array.</u> It will be automatically filled in by OBJECT file generator program. (Leave out as input to file generator.)

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
8	OBJ_NO	Integer	Objective number. This parameter is used to identify the particular objective to be used for a given observation. It will be unique for each IPS attitude and orientation, and also will be unique for a given time period if the target is not inertially fixed, like planets, comets, etc. Note that the sun falls in this category. To determine when or if another objective is needed for the same target but for a different observing time, see item number 24 of this table and assess whether or not the guidestars will still appear in the FOV. The range of values is from 1 to 998.
9	EXP_NO	Integer	Experiment number. This parameter is used to determine which experiment is selected. The range is from 1 to 5, with "1" always being assigned to the IPS itself (Boresight FHST LOS pointed to target defined in items 10-12). When another experiment is selected, the IPS will point the experiment LOS (defined by a DCM stored where the experiment LOS is to be pointed).
10	ATT (1)	Array (7) Float Pt. (Scalar Number)	Target Attitude. In Stellar mode, this first element is the target Right Ascension (where the experiment LOS is to be pointed) in deg., relative to either Mission-True-of-Date (MTOD) System (0') or the Aries-Mean-of-Fifty (AM50) System (0"). The choice of reference system is dependent upon crew desires for a particular mission, as long as this reference is used throughout the objective loads (i.e. T_0_01, FHST_STARRA, etc.).  In Solar Mode, this element represents target yaw, measured in arcsec, relative to the Solar Ecliptic System. (For Earth mode, see IPS-DS-MH-0049).



TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
11	(2)	Float Pt.	<u>Target Attitude (Continued)</u> . This is the same as item 10 (ATT (1)) except that in Stellar mode this represents target Declination in deg., and in Solar Mode this represents target pitch, in arcsec. (For Earth Mode, see IPS-DS-MH-0049).
12	(3)	Float Pt.	<u>Target Attitude (Continued)</u> . This is the same as item 10 (ATT (1)) except that in Stellar Mode this represents target Roll in deg., and in Solar Mode this also represents target Roll in deg. (+ 180°). This roll angle is defined as the angle from the meridian plane (Inertial or Solar Ecliptic Z-axis and selected experiment LOS) to the selected experiment Z-axis. A positive angle is defined as a positive rotation of the experiment (or boresight FHST) LOS from the meridian plane to the Experiment Z-axis. If Experiment 1 is selected, the body-fixed reference system to use is the IPS Platform (P) system. (For Earth Mode, see IPS-DS-MH-0049).
13	(4)	Float Pt.	<u>Target Attitude (Continued)</u> . Same as item 10 (ATT (1)).
14	(5)	Float Pt.	<u>Target Attitude (Continued)</u> . Same as item 11 (ATT (2)).
15	(6)	Float Pt.	<u>Target Attitude (Continued)</u> . Same as item 12 (ATT (3)).
16	(7)	Float Pt.	Not used in Stellar and Solar mode. The value should be set to "0".

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
17	SCAN_ROL	Float Pt.	Scan Roll Offset (in deg). This parameter sets the orientation of the scan frame in relation to inertial (or solar-fixed or Earth-fixed) space. A positive offset is a positive rotation about the Experiment (or IPS) LOS. If scanning is not desired for the particular objective, the value should be set to "0".
18	SCAN_LGTH	Float Pt.	Scan Amplitude (in arcmin). This indicates the length of a scan line, with each line being the same size. If scan is not used, the value should be "0".
19	SCAN_RATE	Float Pt.	Scan Rate (in arcmin/sec). This gives the desired scan rate of each line. Note that if scan is desired with optical hold, this rate must be below the max. FHST tracking rate capability. If scan is not used, the value should be 1.0E-6, due to software peculiarities.
20	SCAN_STEP	Float Pt.	Scan Step (in arcmin). This gives the desired distance between successive scan lines. If scan is not used, the value should be "0".
21	SCAN_LINE	Integer	Number of scan lines desired. If scan is not used, the value should be set to "0".
22	SCAN_FRAME	Integer	Number of times the scan field should be scanned. If scan is not used, the value should be set to "1".

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
23	SUN_POS	Array (13) Float. Pt.	<p>Sun position parameters. For Stellar and Earth modes, these parameters should be left out as input to the OBJECT file generator.</p> <p>In Solar mode, this 13 parameter array provides data for interpolation of Sun position. See IPS-DS-MH-0011 for a complete definition of each of the parameters. Note that if these parameters are hand-calculated, it may be sufficient to calculate only 1 set of data for all objective loads, depending upon desired accuracy. However, if done by software it is recommended to use the time interval which defines the roll star(s) capability for the total time interval defining the Sun Position parameter calculations.</p>
24	DCM_T_0_01	Matrix(3,3) Float. Pt.	<p>Target Inertial to IPS Direction Cosine Matrix. This parameter represents a transformation from the inertial reference used (AM50, MTOD, etc.) to the IPS Inertial reference (0) system. See IPS-DS-MH-0011 for calculation of DCM T 0 01. Note that this matrix, as defined for time "t", must not be in error more than 10 deg. by the time it is utilized during the mission, as it would cause instability of the Attitude Determination Filter (See param. ATT_CHECK in the MDP file AGAINs.)</p> <p>If Earth mode is selected leave blank.</p>
25	FHST_STARNO (1)	Array (3) Integer	<p>Star-count parameter. This parameter indicates the number of potential guidestars in the particular objective which are identified for the boresight FHST. For Stellar mode, this value can be 0, 1, or 2 for the special case of OSP calibration, or it can vary between 0 and 7 (inclusive) for operational objectives (IDOP).</p>

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
25 (cont)			For Solar mode, this value is always 1, since the Sun will always be in the tracker FOV.  For Earth mode this parameter is not used, and should be left blank.
26	(2)	Integer	<u>Star-count parameter</u> (Continued). For Stellar mode, this is the same as item 25 (FHST_STARNO(1)) except for the right skewed FHST. For Solar mode, this value can either be 0 or 1. This is not used in Earth mode, and should be left blank.
27	(3)	Integer	<u>Star-count parameter</u> (Continued). This is the same as item 26 (FHST_STARNO(2)) except that it is for the left skewed tracker.
28	FHST_STARRA (1,X)	Matrix(3,7) Array (7) Float. Pt.	<u>Star Right-Ascension</u> . For Stellar mode given an IDIN or IDOP objective, this 7 element array will contain the right-ascension of each potential guidestar (in radians) identified for the boresight tracker, resolved in an inertial (MTOD, AM50, etc.) reference system. If there are less than 7 stars as defined by item 25 above, the remaining elements in this array should be set to zero. If there is more than 1 star identified, the array should be organized such that the brightest star is first and dimmest star is last. In the OSP calibration mode, elements 1 and 2 are the right-ascension of the bright star and dim star respectively in the boresight FHST FOV.

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
28 (cont)			<p>Elements 3 and 4 are the expected "y" and "z" positions (in radians) respectively of the bright star in the boresight FHST FOV, resolved in that tracker's geometric (M) system. Elements 5 and 6 are the same as elements 3 and 4 except they pertain to the dim star. Element 7 should be left blank.</p> <p>For Solar and Earth modes, all 7 elements should be left blank.</p>
29	(2, X)	Array (7) Float. Pt.	<p>Star Right-Ascension (Continued). For Stellar mode, this is the same as item 28 (FHST_STARRA (1,X)) except everything pertains to the right-skewed tracker. For Solar mode, element 1 will contain the star right-ascension (in radians) for the guidestar in the right tracker, resolved in an inertial (MTOD, AM50, etc.) reference system. If no star has been identified for the right tracker as defined by item 26 (FHST_STARNO(2)), then this should be left blank. The other 6 elements should be left blank.</p> <p>For Earth mode, all 7 elements should be left blank.</p>
30	(3, X)	Array (7) Float. Pt.	<p>Star Right-Ascension (Continued). This is the same as item 29 (FHST_STARRA (2,X)) except that it is for the left skewed tracker.</p>

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
31	FHST STARDEC (1,X)	Matrix (3,7) Array (7) Float. Pt.	<p>Star Declination. For Stellar mode given an IDIN or IDOP objective, this 7 element array will contain the declination of each potential guidestar (in radians) identified for the boresight tracker, resolved in an inertial (MTOD, AM50, etc.) reference system. If there are less than 7 stars as defined by item 25 above, the remaining elements in this array should be set to zero. If there is more than 1 star identified, the array should be organized such that the brightest star is first and dimmest star is last. In the OSP calibration mode, elements 1 and 2 are the declinations of the bright star and dim star respectively in the boresight FHST FOV. Elements 3 through 7 should be left blank.</p> <p>For Solar and Earth modes, all 7 elements should be left blank.</p>
32	(2,X)	Array (7)	<p>Star Declination (Continued). This is the same as item 31 (FHST_STARDEC (1,X)) except that it is for the right skewed tracker.</p>
33	(3,X)	Array (7) Float. Pt.	<p>Star Declination (Continued). This is the same as item 31 (FHST_STARDEC (1,X)) except that it is for the left skewed tracker.</p>

TABLE VIII-1. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
34	FHST_CR_CMD (1,X)	Matrix (3,7) Array (7) Integer	<p>Star Countrates. For Stellar mode given an IDIN or IDOP objective, this 7 element array will contain the star magnitude (expressed as a countrate) for each potential guidestar identified for the boresight tracker. In IDOP if there are less than 7 stars defined by item 25 above, the remaining elements in this array should be set to zero. In IDIN if there are no stars identified for a given objective, the first element should be set to 32767, with the rest of the elements blank.</p> <p>Note that conversion between magnitude and countrate is FHST, position, and star temperature dependent; the conversion equations are given in IPS-SED-04, Vol. 3, FHST User's Manual-FMX-Specific Parameters.</p> <p>In Solar mode, element 1 should contain the countrate of the Sun, with all other elements blank. The Sun countrate is FHST model and Sun beam splitter-dependent, and is found in IPS-SED-04, Vol. 3 for the particular boresight FHST.</p> <p>In Earth mode, leave all elements blank.</p>

TABLE VIII-1. (Concluded)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
35	(2,X)	Array (7) Integer	<p>Star Countrates (Continued). For Stellar mode, this is the same as item 34 (FHST_CR_CMD(1, X)) except relative to the right skewed tracker.</p> <p>For Solar mode, element 1 of the 7 element matrix should contain the star countrate of the guidestar identified for the right skewed tracker; with all other elements left blank. If there is no star identified for the right tracker for a particular objective, element 1 should be set to 32767 with the remaining elements blank. (This allows the tracker to continually be in search mode so that it can send housekeeping data to the Subsystem Computer.)</p> <p>In Earth mode, leave all elements blank.</p>
36	(3,X)	Array (7) Integer	<p>Star Countrates (Continued). This is the same as item 35 (FHST_CR_CMD(2,X)) except relative to the left skewed tracker.</p>

NOTE: FOR MORE INFORMATION, SEE IPS-DS-SP-109.2, SPECIFICATION OF COMPOOLS (PART 2: COMPOOL COBJ), IPS-DS-MH-0049, OBJGEN SOFTWARE USERS MANUAL, IPS-DS-MH-0011, HOW TO GENERATE MISSION DEPENDENT PARAMETERS, OR IPS-SED-04, VOLUME 3, FHST USER'S MANUAL-FMX-SPECIFIC PARAMETERS.



TABLE VIII-2. DEFINITION OF OBJECTIVE LOADS PARAMETERS 28-36 FOR  
THE MODES IDIN, IDOP, AND OSPCAL

No.	Tracker	IDIN Mode							OSPCAL Mode							IDOP Mode*						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
28	BST	$\alpha_{M50}$							$\alpha_{BS}$	$\alpha_{DS}$	Y BS	Z BS	Y DS	Z DS		$\alpha_1$	$\alpha_2$	$\alpha_3$	$\alpha_4$	$\alpha_5$	$\alpha_6$	$\alpha_7$
29	RST	$\alpha_{M50}$							$\alpha_{BS}$	$\alpha_{DS}$	Y BS	Z BS	Y DS	Z DS								
30	LST	$\alpha_{M50}$							$\alpha_{BS}$	$\alpha_{DS}$	Y BS	Z BS	Y DS	Z DS								
31	BST	$\delta_{M50}$							$\delta_{BS}$	$\delta_{DS}$						$\delta_1$	$\delta_2$	$\delta_3$	$\delta_4$	$\delta_5$	$\delta_6$	$\delta_7$
32	RST	$\delta_{M50}$							$\delta_{BS}$	$\delta_{DS}$												
33	LST	$\delta_{M50}$							$\delta_{BS}$	$\delta_{DS}$												
34	BST	CR							CR <sub>BS</sub>	CR <sub>DS</sub>						CR <sub>1</sub>	CR <sub>2</sub>	CR <sub>3</sub>	CR <sub>4</sub>	CR <sub>5</sub>	CR <sub>6</sub>	CR <sub>7</sub>
35	RST	CR							CR <sub>BS</sub>	CR <sub>DS</sub>												
36	LST	CR							CR <sub>BS</sub>	CR <sub>DS</sub>												

BST - Boresight Tracker  
RST - Right Skewed Tracker  
LST - Left Skewed Tracker

$\alpha$  - Right Ascension  
 $\delta$  - Declination  
CR - Count Rate

BS - Bright Star  
DS - Dim Star

\* Up to 7 stars may be on  
the objective load for each  
tracker in the IDOP Mode.  
There may be fewer than this  
number, even zero.

TABLE VIII-3. EXAMPLE IDIN OBJECTIVE LOAD

GENERATE FILE - OBJECT, FC - IPSFLI		
DEFINE OBJ- 1		
ST_MODE	- 1	HST_STARRA(1,4)
ST_IDOP_IDIN	- 0	FHST_STARRA(1,5)
SO_MODE	- 0	FHST_STARRA(1,6)
SO_ROLCTR_LOS	- 0	FHST_STARRA(1,7)
EA_MODE	- 0	FHST_STARRA(2,1)
EA_LMLUM	- 0	FHST_STARRA(2,2)
EXP_NO	- 1	FHST_STARRA(2,3)
ATT(1)	- 0.14516740E+01	FHST_STARRA(2,4)
ATT(2)	- 0.28812185E+02	FHST_STARRA(2,5)
ATT(3)	- -0.16587628E+03	FHST_STARRA(2,6)
ATT(4)	- 0.14516740E+01	FHST_STARRA(2,7)
ATT(5)	- 0.28812185E+02	FHST_STARRA(3,1)
ATT(6)	- -0.16587628E+03	FHST_STARRA(3,2)
ATT(7)	- 0.00000000E+00	FHST_STARRA(3,3)
SCAN_ROL	- 0.00000000E+00	FHST_STARRA(3,4)
SCAN_LGTH	- 0.00000000E+00	FHST_STARRA(3,5)
SCAN_RATE	- 0.00000000E+00	FHST_STARRA(3,6)
SCAN_STEP	- 0.10000000E-05	
SCAN_LINE	- 0.00000000E+00	
SCAN_FRAME	- 1	
DCM_T-0-01(1,1)	- 0.87592298E+00	
DCM_T-0-01(1,2)	- 0.22197565E-01	
DCM_T-0-01(1,3)	- 0.48194006E+00	
DCM_T-0-01(2,1)	- 0.14213155E+00	
DCM_T-0-01(2,2)	- -0.96648055E+00	
DCM_T-0-01(2,3)	- -0.21380830E+00	
DCM_T-0-01(3,1)	- 0.46103966E+00	
DCM_T-0-01(3,2)	- 0.25577849E+00	
DCM_T-0-01(3,3)	- -0.84971750E+00	
FHST_STARNO(1)	- 1	
FHST_STARNO(2)	- 1	
FHST_STARNO(3)	- 0	
FHST_STARRA(1,1)	- 0.25336491E-01	
FHST_STARRA(1,2)	- 0.00000000E+00	
FHST_STARRA(1,3)	- 0.00000000E+00	

TABLE VIII 3. (Concluded)

FHST-STARDEC(3,7)	-	0.00000000E+00	HST_CR_CMD(3,2)	-	0
FHST-STARDEC(1,1)	-	0.50286752E+00	FHST_CR_CMD(3,3)	-	0
FHST-STARDEC(1,2)	-	0.00000000E+00	FHST_CR_CMD(3,4)	-	0
FHST-STARDEC(1,3)	-	0.00000000E+00	FHST_CR_CMD(3,5)	-	0
FHST-STARDEC(1,4)	-	0.00000000E+00	FHST_CR_CMD(3,6)	-	0
FHST-STARDEC(1,5)	-	0.00000000E+00	FHST_CR_CMD(3,7)	-	0
FHST-STARDEC(1,6)	-	0.00000000E+00			
FHST-STARDEC(1,7)	-	0.00000000E+00			
FHST-STARDEC(2,1)	-	0.00000000E+00			
FHST-STARDEC(2,2)	-	0.68389696E+00			
FHST-STARDEC(2,3)	-	0.00000000E+00			
FHST-STARDEC(2,4)	-	0.00000000E+00			
FHST-STARDEC(2,5)	-	0.00000000E+00			
FHST-STARDEC(2,6)	-	0.00000000E+00			
FHST-STARDEC(2,7)	-	0.00000000E+00			
FHST-STARDEC(3,1)	-	0.00000000E+00			
FHST-STARDEC(3,2)	-	0.00000000E+00			
FHST-STARDEC(3,3)	-	0.00000000E+00			
FHST-STARDEC(3,4)	-	0.00000000E+00			
FHST-STARDEC(3,5)	-	0.00000000E+00			
FHST-STARDEC(3,6)	-	0.00000000E+00			
FHST-STARDEC(3,7)	-	0.00000000E+00			
FHST_CR_CMD(1,1)	-	2628			
FHST_CR_CMD(1,2)	-	0			
FHST_CR_CMD(1,3)	-	0			
FHST_CR_CMD(1,4)	-	0			
FHST_CR_CMD(1,5)	-	0			
FHST_CR_CMD(1,6)	-	0			
FHST_CR_CMD(1,7)	-	0			
FHST_CR_CMD(2,1)	-	112			
FHST_CR_CMD(2,2)	-	0			
FHST_CR_CMD(2,3)	-	0			
FHST_CR_CMD(2,4)	-	0			
FHST_CR_CMD(2,5)	-	0			
FHST_CR_CMD(2,6)	-	0			
FHST_CR_CMD(2,7)	-	0			
FHST_CR_CMD(3,1)	-	32767			

M4>

TABLE VIII-4. EXAMPLE IDOP OBJECTIVE LOAD

GENERATE FILE - OBJECT, FC - IPSFLI			
DEFINE OBJ-707			
ST_MODE	- 1	HST_STARRA(1,3)	- 0.52499337E+01
ST_IDOP_IDIN	- 1	FHST_STARRA(1,4)	- 0.00000000E+00
SO_MODE	- 0	FHST_STARRA(1,5)	- 0.00000000E+00
SO_ROLCTR_LOS	- 0	FHST_STARRA(1,6)	- 0.00000000E+00
EA_MODE	- 0	FHST_STARRA(1,7)	- 0.00000000E+00
EA_LMLUM	- 0		
OBJ_NO	- 707		
EXP_NO	- 2	FHST_STARRA(2,1)	- 0.54490948E+01
ATT(1)	- 0.59297028E+02		
ATT(2)	- 0.21508030E+02	FHST_STARRA(2,2)	- 0.54479165E+01
ATT(3)	- 0.10339970E+03		
ATT(4)	- 0.59297028E+02	FHST_STARRA(2,3)	- 0.54480658E+01
ATT(5)	- 0.21508030E+02		
ATT(6)	- 0.10339970E+03	FHST_STARRA(2,4)	- 0.54414659E+01
ATT(7)	- 0.00000000E+00		
SCAN_ROL	- 0.00000000E+00	FHST_STARRA(2,5)	- 0.54583654E+01
SCAN_LGTH	- 0.00000000E+00		
SCAN_RATE	- 0.10000000E-05	FHST_STARRA(2,6)	- 0.00000000E+00
SCAN_STEP	- 0.00000000E+00		
SCAN_LINE	- 0	FHST_STARRA(2,7)	- 0.00000000E+00
SCAN_FRAME	- 1		
DCM_T-0-01(1,1)	- 0.47452423E+00	FHST_STARRA(3,1)	- 0.50760312E+01
DCM_T-0-01(1,2)	- 0.80068564E+00		
DCM_T-0-01(1,3)	- 0.36569017E+00	FHST_STARRA(3,2)	- 0.50725393E+01
DCM_T-0-01(2,1)	- 0.20401178E-01		
DCM_T-0-01(2,2)	- 0.42533487E+00	FHST_STARRA(3,3)	- 0.50770545E+01
DCM_T-0-01(2,3)	- 0.90480608E+00		
DCM_T-0-01(3,1)	- 0.88000596E+00	FHST_STARRA(3,4)	- 0.50496821E+01
DCM_T-0-01(3,2)	- 0.42189187E+00		
DCM_T-0-01(3,3)	- 0.21816663E+00	FHST_STARRA(3,5)	- 0.00000000E+00
FHST_STARNO(1)	- 3		
FHST_STARNO(2)	- 5	FHST_STARRA(3,6)	- 0.00000000E+00
FHST_STARNO(3)	- 4		
FHST_STARRA(1,1)	- 0.52448401E+01	FHST_STARRA(3,7)	- 0.00000000E+00
FHST_STARRA(1,2)	- 0.52516980E+01		

TABLE VIII 4. (Concluded)

FHST-STARDEC(1,1)	-0.37449390E+00	HST_CR_CMD(3,3)	-	55
FHST-STARDEC(1,2)	-0.38085416E+00	FHST_CR_CMD(3,4)	-	18
FHST-STARDEC(1,3)	-0.36904705E+00	FHST_CR_CMD(3,5)	-	0
FHST-STARDEC(1,4)	0.00000000E+00	FHST_CR_CMD(3,6)	-	0
FHST-STARDEC(1,5)	0.00000000E+00	FHST_CR_CMD(3,7)	-	0
FHST-STARDEC(1,6)	0.00000000E+00			
FHST-STARDEC(1,7)	0.00000000E+00			
FHST-STARDEC(2,1)	-0.47311637E+00			
FHST-STARDEC(2,2)	-0.47879484E+00			
FHST-STARDEC(2,3)	-0.49189210E+00			
FHST-STARDEC(2,4)	-0.48091555E+00			
FHST-STARDEC(2,5)	-0.46268359E+00			
FHST-STARDEC(2,6)	0.00000000E+00			
FHST-STARDEC(2,7)	0.00000000E+00			
FHST-STARDEC(3,1)	-0.26448151E+00			
FHST-STARDEC(3,2)	-0.24429621E+00			
FHST-STARDEC(3,3)	-0.25572792E+00			
FHST-STARDEC(3,4)	-0.25388107E+00			
FHST-STARDEC(3,5)	0.00000000E+00			
FHST-STARDEC(3,6)	0.00000000E+00			
FHST-STARDEC(3,7)	0.00000000E+00			
FHST_CR_CMD(1,1)	29			
FHST_CR_CMD(1,2)	14			
FHST_CR_CMD(1,3)	13			
FHST_CR_CMD(1,4)	0			
FHST_CR_CMD(1,5)	0			
FHST_CR_CMD(1,6)	0			
FHST_CR_CMD(1,7)	0			
FHST_CR_CMD(2,1)	331			
FHST_CR_CMD(2,2)	34			
FHST_CR_CMD(2,3)	28			
FHST_CR_CMD(2,4)	25			
FHST_CR_CMD(2,5)	14			
FHST_CR_CMD(2,6)	0			
FHST_CR_CMD(2,7)	0			
FHST_CR_CMD(3,1)	129			
FHST_CR_CMD(3,2)	128			

TABLE VIII-5. EXAMPLE OSPCAL OBJECTIVE LOAD

GENERATE FILE -	OBJECT, FC -	IPSFLI	
DEFINE OBJ-247			
ST_MODE	1		HST_STARRA(1,3)
ST_IDOP_IDIN	0		FHST_STARRA(1,4)
SO_MODE	0		FHST_STARRA(1,5)
SO_ROLCTR_LOS	0		FHST_STARRA(1,6)
EA_MODE	0		FHST_STARRA(1,7)
EA_LMLUM	0		FHST_STARRA(2,1)
OBJ_NO	247		FHST_STARRA(2,2)
EXP_NO	1		FHST_STARRA(2,3)
ATT(1)		-0.13471661E+03	FHST_STARRA(2,4)
ATT(2)		-0.25087257E+02	FHST_STARRA(2,5)
ATT(3)		0.14376602E+03	FHST_STARRA(2,6)
ATT(4)		-0.13471661E+03	FHST_STARRA(2,7)
ATT(5)		-0.25087257E+02	FHST_STARRA(3,1)
ATT(6)		0.14376602E+03	FHST_STARRA(3,2)
ATT(7)		0.00000000E+00	FHST_STARRA(3,3)
SCAN_ROL		0.00000000E+00	FHST_STARRA(3,4)
SCAN_LGTH		0.00000000E+00	FHST_STARRA(3,5)
SCAN_RATE		0.10000000E-05	FHST_STARRA(3,6)
SCAN_STEP		0.00000000E+00	FHST_STARRA(3,7)
SCAN_LINE	0		
SCAN_FRAME	1		
DCM_T-0-01(1,1)		-0.63722533E+00	
DCM_T-0-01(1,2)		-0.64356011E+00	
DCM_T-0-01(1,3)		-0.42399803E+00	
DCM_T-0-01(2,1)		-0.74950868E+00	
DCM_T-0-01(2,2)		0.38944298E+00	
DCM_T-0-01(2,3)		0.53532314E+00	
DCM_T-0-01(3,1)		-0.17938954E+00	
DCM_T-0-01(3,2)		0.65891165E+00	
DCM_T-0-01(3,3)		-0.73051679E+00	
FHST-STARN0(1)	2		
FHST-STARN0(2)	2		
FHST-STARN0(3)	2		
FHST-STARRA(1,1)		0.39319367E+01	
FHST-STARRA(1,2)		0.39394133E+01	

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TABLE VIII-5. (Concluded)

FHST-STARDEC(1,1)	-0.43785638E+00	HST_CR_CMD(3,3)	-	0
FHST-STARDEC(1,2)	-0.44674313E+00	FHST_CR_CMD(3,4)	-	0
FHST-STARDEC(1,3)	0.00000000E+00	FHST_CR_CMD(3,5)	-	0
FHST-STARDEC(1,4)	0.00000000E+00	FHST_CR_CMD(3,6)	-	0
FHST-STARDEC(1,5)	0.00000000E+00	FHST_CR_CMD(3,7)	-	0
FHST-STARDEC(1,6)	0.00000000E+00			
FHST-STARDEC(1,7)	0.00000000E+00			
FHST-STARDEC(2,1)	-0.41592929E+00			
FHST-STARDEC(2,2)	-0.40812758E+00			
FHST-STARDEC(2,3)	0.00000000E+00			
FHST-STARDEC(2,4)	0.00000000E+00			
FHST-STARDEC(2,5)	0.00000000E+00			
FHST-STARDEC(2,6)	0.00000000E+00			
FHST-STARDEC(2,7)	0.00000000E+00			
FHST-STARDEC(3,1)	-0.46153980E+00			
FHST-STARDEC(3,2)	-0.47171402E+00			
FHST-STARDEC(3,3)	0.00000000E+00			
FHST-STARDEC(3,4)	0.00000000E+00			
FHST-STARDEC(3,5)	0.00000000E+00			
FHST-STARDEC(3,6)	0.00000000E+00			
FHST-STARDEC(3,7)	0.00000000E+00			
FHST_CR_CMD(1,1)	882			
FHST_CR_CMD(1,2)	44			
FHST_CR_CMD(1,3)	0			
FHST_CR_CMD(1,4)	0			
FHST_CR_CMD(1,5)	0			
FHST_CR_CMD(1,6)	0			
FHST_CR_CMD(1,7)	0			
FHST_CR_CMD(2,1)	104			
FHST_CR_CMD(2,2)	31			
FHST_CR_CMD(2,3)	0			
FHST_CR_CMD(2,4)	0			
FHST_CR_CMD(2,5)	0			
FHST_CR_CMD(2,6)	0			
FHST_CR_CMD(2,7)	0			
FHST_CR_CMD(3,1)	1203			
FHST_CR_CMD(3,2)	217			

## IX. IPS GIMBAL ANGLES

A computer program has been designed and coded for the ASTRO mission to determine IPS gimbal angles from position angles and vice-versa. The program is called GIMOP (GIMbal angle Optimization Program), which is a module of GSOLP (Guide Star Objective Load Program).

It is designed to calculate the IPS gimbal angles elevation (EL), cross-elevation (XL), and roll (RL) given (1) the target being observed ( $\alpha, \delta$ ); (2) the orbiter attitude (P, Y, R); and (3) the guidestar that the right tracker is centered on or equivalently, the position angle of the right tracker.

The second option does essentially the opposite job; i.e., given (1) the target being observed ( $\alpha, \delta$ ), (2) the orbiter attitude (P, Y, R), and (3) the IPS gimbal angles (EL, XL, RL), it calculates the corresponding position angle (of the right tracker).

The equations developed below are the bases for both options. The program runs in interactive mode with file inputs from other programs such as PROCAM for Orbiter attitudes and ASTRON for scheduled targets.

Determination of the Elevation (EL), Cross Elevation (XL), and Roll (RL) Angles of the IPS as Measured in the Control Torque Actuator and Resolver System (C-system) on the ASTRO Mission

A unit vector to a stellar target in the inertial system is given by (Fig. 23):

$$S_I = \begin{pmatrix} \cos \alpha \cos \delta \\ \sin \alpha \cos \delta \\ \sin \delta \end{pmatrix} \quad (27)$$

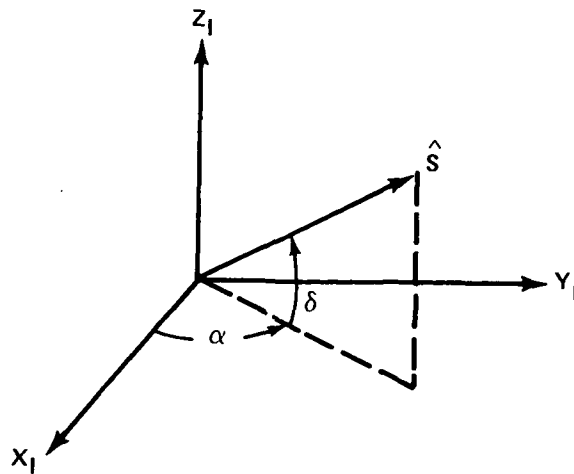


Figure 23. Position of a star in the inertial system.



This same stellar target has a unit vector in the orbiter body system given by the equation

$$\hat{S}_B = C \hat{S}_I \quad (28)$$

where C is the transformation matrix computed from PROCAM and dependent on the orbiter attitude: i.e.,  $[C = (R)_x (Y)_z (P)_y]$ . This matrix can also be computed from the quaternion if it is known.

The azimuth and co-elevation of the stellar target in the body system is given by the equations (Fig. 24)

$$AZ_S = \tan^{-1} (-Y_{SB}/X_{SB})$$

$$Coel_S = \cos^{-1} (-Z_{SB}) \quad (29)$$

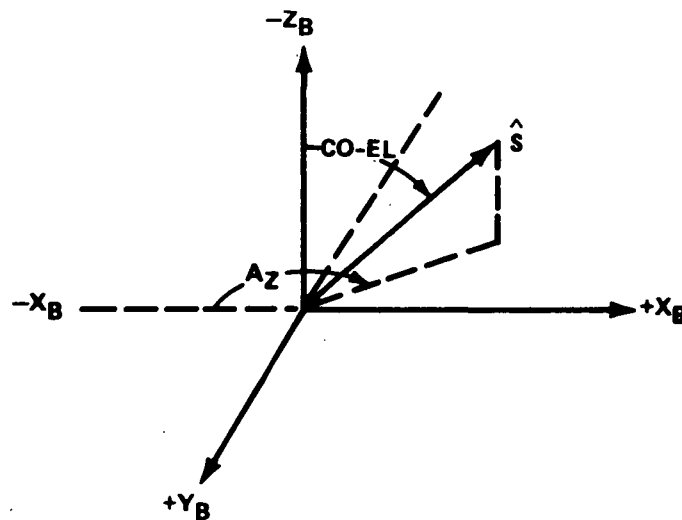


Figure 24. Illustration of position of a star in the orbiter body coordinate system (AZ and CO-EL).

A unit vector to the stellar target in the body system is given by equation (28) or in terms of Az and coel as

$$\begin{aligned} \hat{S}_B &= \hat{i} (-\sin coEL_S \cos AZ_S) + \hat{j} (-\sin coEL_S \sin AZ_S) + \hat{k} (-\cos coEL_S) \\ &= \begin{pmatrix} -\sin coEL_S \cos AZ_S \\ -\sin coEL_S \sin AZ_S \\ -\cos coEL_S \end{pmatrix} \end{aligned} \quad (30)$$

The C-system (Control Torque Actuator and Resolver System) described in Section 1.8 of Reference 8 is mounted on the orbiter for the ASTRO mission in its "cradle position" as shown in Figure 25.

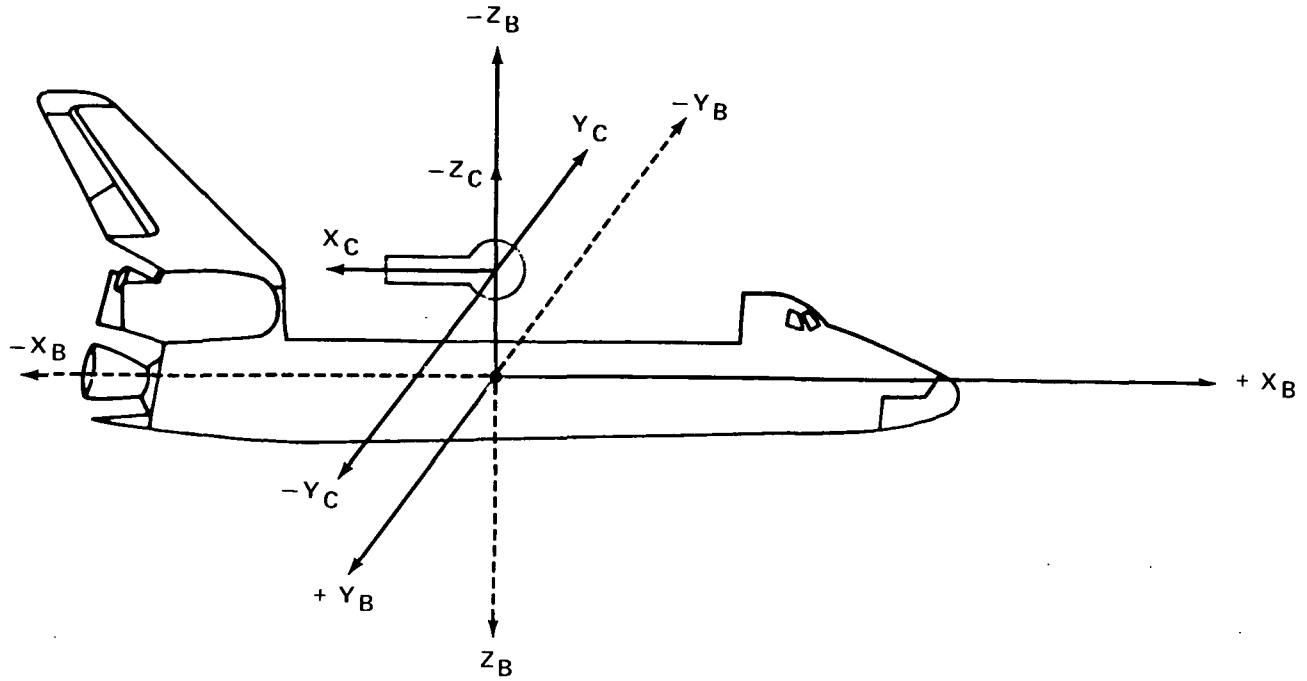


Figure 25. Orbiter body system and C-system in cradle position.

The transformation of a unit vector from the Body Coordinate System to the IPS C-system in the cradle position is given by the equation

$$\hat{S}_C = (180^\circ)_Z \hat{S}_B \quad (31)$$

and from the inertial system to the C-system cradle position is

$$\hat{S}_C = (180^\circ)_Z C \hat{S}_I \quad (32)$$

The IPS has three orthogonal gimbal axes. Rotations about these axes are elevation (EL) about the Y-axis, cross elevation (XL) about  $Z_C$ -axis, and roll (RL) about the  $X_C$ -axis all measured in the positive (right-hand) sense.

In order for the IPS to point its x-axis ( $X_C$ ) at some stellar target when the orbiter is in an inertial attitude, it must execute an elevation and a cross elevation maneuver until the x-axis is on target. A roll about the x-axis will then not affect the x-axis pointing direction but it will alter the positions of the skewed star trackers.

Assume that a stellar target has some arbitrary position with respect to the body coordinates,  $S_B$ , as shown in Figure 26.

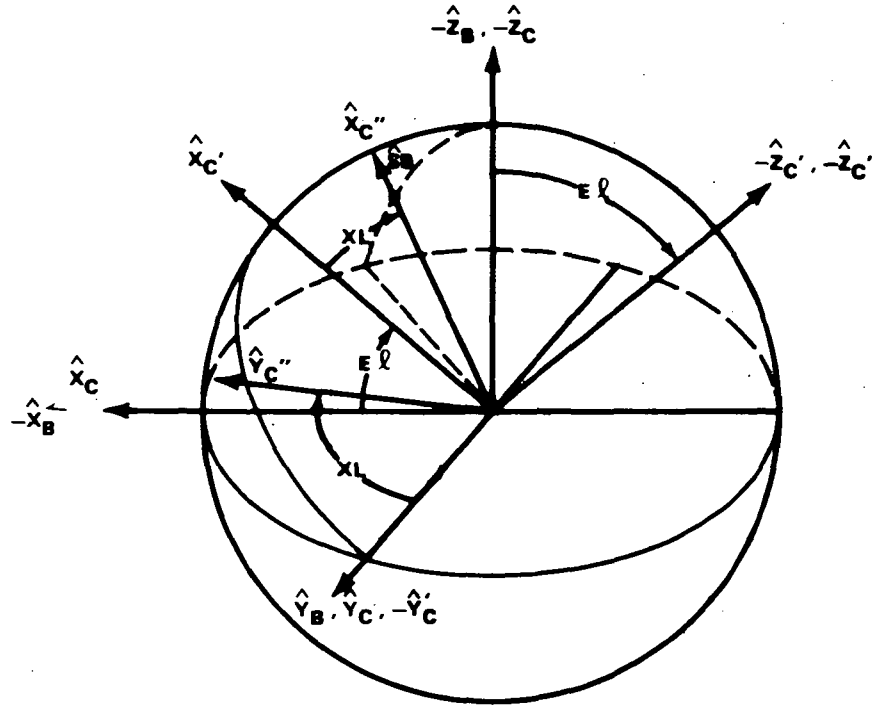


Figure 26. EL and XL angles of IPS to point at  $\hat{S}_B$ .

The first question to be answered is: what elevation, EL, is required to put the stellar vector  $S_B$  in the plane defined by the IPS  $X_C'$  and  $Y_C'$  axes or such that it is perpendicular to the IPS  $Z_C'$  axis?

In the body system the  $-Z_C'$  axis (after the EL maneuver) would be represented by the equation

$$-\hat{Z}_{C'B} = \hat{i} \sin EL + \hat{j} (0) + \hat{k} (-\cos EL) = \begin{pmatrix} \sin EL \\ 0 \\ -\cos EL \end{pmatrix} \quad (33)$$

In this position, then,  $-Z_C'$  and  $S_B$  are perpendicular so the following condition holds where one can use equation (28) or equation (30) for  $S_B$

$$-\hat{Z}_{C'B} \cdot \hat{S}_B = 0 = \sin EL \sin \text{coel}_S \cos AZ_S + \cos EL \cos \text{coel}_S$$

or

$$0 = \sin EL \cdot S_{XB} - \cos EL \cdot S_{ZB} \quad .$$

These equations give

$$EL = \tan^{-1} (\cos coELs / \sin coELs \cos AZ_S) = \tan^{-1} (-S_{ZB} / -S_{XB}) \quad . \quad (34)$$

The second expression where  $S_B$  is taken from equation (28) may give better numerical results.

The  $\hat{Y}_C$  and  $\hat{Y}_{C'}$  axes in the body system (both before and after the elevation maneuver) are

$$\hat{Y}_{CB} = \hat{Y}_{C'B} = \begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix} \quad . \quad (35)$$

From inspection of Figure 26 and from equations (30) and (35) one can write

$$\hat{Y}_{C'B} \cdot \hat{S}_B = \sin coELs \sin AZ_S = \cos (\pi/2 - XL) = \sin XL$$

or

$$XL = \sin^{-1} (\sin coELs \sin AZ_S) \quad . \quad (36)$$

Using equation (28) for  $S_B$  instead of equation (30) gives

$$\hat{Y}_{C'B} \cdot \hat{S}_B = -SY_B = \cos (\pi/2 - SL) = \sin XL \quad \text{or} \quad XL = \sin^{-1} [-SY_B] \quad (37)$$

Again, equation (37) may give better numerical accuracy than equation (36).

The ASTRO payload complement, as currently mounted on the IPS, is as shown in Figure 1A. Note that the OSP is rotated by 225 deg about the x-axis from the "Top" position.

Unit vectors pointing to the OSP right skewed tracker, boresight tracker, and left skewed tracker expressed in orbiter body coordinates when the IPS is in the "cradle" position are

$$\hat{RS}_B = (225^\circ)_x \begin{pmatrix} -\cos 12^\circ \\ -\sin 12^\circ \\ 0 \end{pmatrix} ;$$

$$\hat{BS}_B = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} ;$$

$$\hat{LS}_B = (225^\circ)_x \begin{pmatrix} -\cos 12^\circ \\ \sin 12^\circ \\ 0 \end{pmatrix} ;$$

(38)

$$\hat{RS}_B = \begin{pmatrix} -\cos 12^\circ \\ -\sin 12^\circ \cos 225^\circ \\ \sin 12^\circ \sin 225^\circ \end{pmatrix} ;$$

$$\hat{BS}_B = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} ;$$

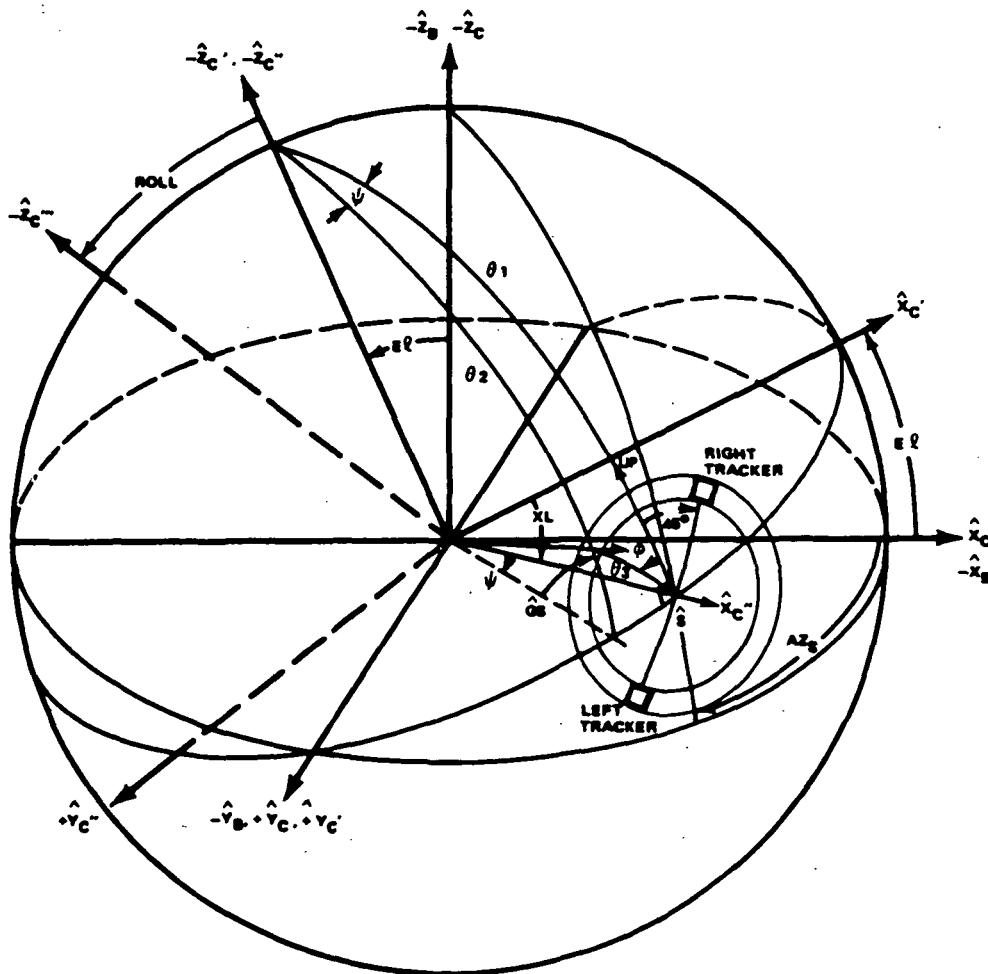
$$\hat{LS}_B = \begin{pmatrix} -\cos 12^\circ \\ +\sin 12^\circ \cos 225^\circ \\ -\sin 12^\circ \sin 225^\circ \end{pmatrix} ;$$

These vectors expressed in the C-system in the cradle position are obtained by applying the transformation in equation (31), i.e.,

$$\hat{RS}_C = (180^\circ)_z \hat{RS}_B = \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} -\cos 12^\circ \\ -\sin 12^\circ \cos 225^\circ \\ \sin 12^\circ \sin 225^\circ \end{pmatrix} = \begin{pmatrix} \cos 12^\circ \\ \sin 12^\circ \cos 225^\circ \\ \sin 12^\circ \sin 225^\circ \end{pmatrix}$$

$$\hat{L}S_C = (180^\circ)_z \hat{L}S_B = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} -\cos 12^\circ \\ +\sin 12^\circ \cos 225^\circ \\ -\sin 12^\circ \sin 225^\circ \end{pmatrix} = \begin{pmatrix} \cos 12^\circ \\ -\sin 12^\circ \cos 225^\circ \\ -\sin 12^\circ \sin 225^\circ \end{pmatrix}$$

Figure 27 shows the position of the IPS relative to the Orbiter body coordinates after the elevation and cross-elevation maneuvers but prior to any roll maneuver.



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Any inertial target  $S_I$  is transformed to the body system by equation (28) and then to the C-system by equation (32). It is then transformed to the C" system by the two additional rotations EL about the Y-axis and the XL about the Z-axis; i.e.,

$$\hat{S}_{C''} = (XL)_Z (EL)_Y (180^\circ)_Z \hat{CS}_I \quad (40)$$

This transformation applies to any inertial target including guide stars which may fall in the annulus shown in Figure 27.

If one wanted to center the right tracker on a guide star as shown in Figure 27, one would then have to do a roll about the X-axis of 45 deg plus the angle  $\phi$ . The next task is then to calculate  $\phi$ .

In the spherical triangle formed by the  $-Z_{C''}$  axis, the  $X_{C''}$  axis, and the guide star, GS, in the annulus, the various angles are:

$$\theta_1 = 90^\circ$$

$$\theta_3 = \cos^{-1} (\hat{S} \cdot \hat{GS}) = \cos^{-1} [\cos(\alpha_s - \alpha_g) \cos \delta_s \cos \delta_g + \sin \delta_s \sin \delta_g] \quad (41)$$

$$\theta_2 = \cos^{-1} (\hat{GS} \cdot \hat{-Z}_{C''}) = \cos^{-1} (-\hat{GS}_{Z_{C''}})$$

This last quantity is the Z component of the guide star unit vector in the C" system. The total guide star vector in the C" system is given by equation (40) applied to the guide star and then  $\theta_2$  is calculated by taking the inverse cosine of the Z-component of that vector, i.e.,

$$\hat{GS}_{C''} = (XL)_Z (EL)_Y (180^\circ)_Z \hat{CS}_I \quad (42)$$

Applying the law of cosines for sides to the spherical triangle under discussion gives

$$\cos \theta_2 = \cos \theta_1 \cos \theta_3 + \sin \theta_1 \sin \theta_3 \cos \phi$$

which yields

$$\phi = \cos^{-1} [(\cos \theta_2 - \cos \theta_1 \cos \theta_3) / \sin \theta_1 \sin \theta_3] = \cos^{-1} (\cos \theta_2 / \sin \theta_3) \quad (43)$$

The last step follows because  $\theta_1 = 90$  deg.

It is obvious from Figure 27 and equation (43) that the angle  $\phi$  is always calculated between 0 deg and 180 deg with no "sense-of-direction." Therefore, one must make another test to determine if it should be counted as negative or positive in calculating the roll angle.

A way to make this test is to calculate an angle  $\psi$  shown in Figure 27. From the X and Y components of the guide star GS in the C'' system, i.e., using the components of the vector from equation (42)

$$\psi = \tan^{-1} (GS_{YC''}/GS_{XC''}) \quad (44)$$

Then, if  $\psi > 0$

$$RL = \pi/4 + \phi$$

or if  $\psi < 0$

$$RL = \pi/4 - \phi \quad (45)$$

These are roll angles required to put the right tracker on any given guide star as transformed by equation (42). To put the left tracker on this star, one would have to either add or subtract 180 deg from the roll angles given by equations (45).

The equation required to transform any stellar vector from the inertial system to the C''' system would then have one more rotation, roll, added to equation (42), i.e., it would be

$$\hat{S}_{C'''} = (RL)_X (XL)_Z (EL)_Y (180^\circ)_Z C \hat{S}_I \quad (46)$$

### Verification of Pointing

In the IPS Control Torque Actuator and Resolver system (C-system) and in all of its subsequent rotations, unit vectors to the right-skewed boresight and left-skewed trackers are given by equations (39).

The transformation from the final position of the C-system (i.e., the C'''-system) back to the inertial system is given by the inverse of equation (46)

$$\hat{S}_I = C^T (180^\circ)_Z^T (EL)_Y^T (XL)_Z^T (RL)_X^T \hat{S}_{C'''} \quad (47)$$

This equation can be used to verify pointing, i.e., if it is thought that one of the star trackers is pointing to a particular spot on the sky one can simply plug in the coordinates of the star tracker in question [from equation (30)] in the  $\hat{S}_{C'''}$



position in equation (47) and perform the indicated matrix multiplication and calculate the right ascension and declination of the pointing direction of that tracker. This will then confirm the pointing direction.

### Test Case

In one of the current timelines at an MET = 61.708 hours, the following star and orbiter attitude was scheduled:

$$\alpha_{S50} = 80.^{\circ}78327$$

Star:

Bet - Tau

$$\delta S_{50} = 28.^{\circ}56719$$

The orbiter attitude was:

$$P = 59.^{\circ}888$$

$$Y = 21.^{\circ}591$$

$$R = 111.^{\circ}1978$$

and the C matrix from PROCAM was  $[C = (R)_X (Y)_Z (P)_Y]$

$$C = \begin{pmatrix} 0.46648762 & 0.36798215 & -0.80434972 \\ 0.87327045 & -0.33621705 & 0.35264260 \\ -0.14066990 & -0.86691827 & -0.47818902 \end{pmatrix}$$

To calculate the EL and XL for the IPS pointing, we calculated the unit vector in the inertial system from equation (27) as

$$^A S_I = \begin{pmatrix} \cos \alpha \cos \delta \\ \sin \alpha \cos \delta \\ \sin \delta \end{pmatrix} = \begin{pmatrix} 0.1406699 \\ 0.86691824 \\ 0.478189 \end{pmatrix}$$

Note that this vector is the negative of the last row of the C-matrix. This vector in the orbiter body system, by equation (28), is

$$\hat{S}_B = C\hat{S}_I = \begin{pmatrix} -3.486 \times 10^{-8} \\ 3.565 \times 10^{-8} \\ -0.9999999 \end{pmatrix}$$

Note that the X and Y values are essentially zero and that the Z value is essentially -1, indicating that the orbiter -Z axis is pointing at this star.

The elevation and cross elevation of the IPS, as calculated from equations (34) and (37), are

$$EL = \tan^{-1} [-S_{ZB}/-S_{XB}] = \tan^{-1} [0.9999999/3.486 \times 10^{-8}] \approx 90^\circ$$

$$XL = \sin^{-1} [-SY_B] = \sin^{-1} [-3.565 \times 10^{-8}] \approx 0^\circ$$

The subsequent roll angle will not change the pointing direction for the IPS X-axis, so it is verified at this point that the IPS X-axis is pointing to the correct position in the sky.

#### Verify X-axis Pointing

To verify the X-axis pointing, one uses equation (47) with the proper values inserted into the various matrices, i.e.,

$$\hat{S}_I = C^T (180^\circ)_Z^T (90^\circ)_Y^T (0^\circ)_Z^T (0^\circ)_X^T \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

$$\hat{S}_I = C^T \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = C^T \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

$$\hat{S}_I = C^T \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} = \begin{pmatrix} 0.14066990 \\ 0.86691827 \\ 0.47818902 \end{pmatrix}$$

From which one calculates

$$\alpha = \tan^{-1} (Y/X) = 80.^{\circ}753$$

$$\delta = \sin^{-1} (Z) = 28.^{\circ}567$$

This is indeed pointed at the star Bet-Tau!

Continuing with this test case, it was found that IDOP guide star No. 7 (the first annulus star) on the Beta-Tau science star file was, in true-of-date coordinates,

$$\begin{aligned} \alpha_T &= 82.^{\circ}3435 \\ \delta_T &= 40.^{\circ}5005 \\ \text{Roll} &= 3.^{\circ}737 \end{aligned}$$

This roll angle is the inertial angle measured from North (position angle). In 1950 coordinates,

$$\begin{aligned} \alpha_{50} &= 81.^{\circ}71305 \\ \delta_{50} &= 40.^{\circ}4705 \end{aligned}$$

A unit vector to this guide star in the inertial system is

$$\hat{GS}_I = \begin{pmatrix} \cos \alpha \cos \delta \\ \sin \alpha \cos \delta \\ \sin \delta \end{pmatrix} = \begin{pmatrix} 0.10964611 \\ 0.75279708 \\ 0.64905645 \end{pmatrix}$$

One can now transform this to the 0" system by equation (42)

$$\hat{GS}_{C'} = (0^{\circ})_Z (90^{\circ})_Y (180^{\circ})_Z C \hat{GS}_I$$

$$\hat{GS}_C'' = \begin{pmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} C \hat{G}_{ST}$$

$$\hat{GS}_C'' = \begin{pmatrix} 0 & 0 & -1 \\ 0 & -1 & 0 \\ -1 & 0 & 0 \end{pmatrix} C \hat{GS}_I = \begin{pmatrix} 0.14066990 & 0.86691827 & 0.47818902 \\ -0.87327045 & 0.33621705 & -0.35264260 \\ -0.46648762 & -0.36798215 & 0.80434972 \end{pmatrix} \begin{pmatrix} 0.1096461 \\ 0.7527970 \\ 0.6490564 \end{pmatrix}$$

$$\hat{GS}_C'' = \begin{pmatrix} 0.97840916 \\ -0.071532418 \\ 0.19390392 \end{pmatrix}$$

$$\theta_2 = \cos^{-1} [-G_{SC''Z}] = 101.^\circ 18069$$

$$\theta_3 = \cos^{-1} [S.GS] = 11.^\circ 92772$$

from equation (41) and from equation (43)

$$\phi = \cos^{-1} (\cos \theta_2 / \sin \theta_3) = 159.^\circ 75048$$

$$\psi = \tan^{-1} (GS_{C''Y} / GS_{C''X}) = \tan^{-1} (-0.91532418 / 0.97840916) = -4.^\circ 1815$$

$\psi < 0$ , therefore by equation (45)

$$RL = 45^\circ - \phi = -114.^\circ 75048 = 245^\circ.24952$$

One can now verify if the right tracker is pointed to the guide star by using equation (47) with the proper values inserted.

Inserting the right-skewed tracker as given by equation (39) and the proper angles into equation (47) gives

$$\hat{GS}_I = C^T (180^\circ)_Z^T (90^\circ)_Y^T (0^\circ)_X^T (245.^\circ 24952)_X^T \begin{pmatrix} \cos 12^\circ \\ \sin 12^\circ \cos 225^\circ \\ \sin 12^\circ \sin 225^\circ \end{pmatrix}$$

$$\hat{GS}_I = C^T \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & -0.41866734 & +0.90813966 \\ 0 & -0.90813966 & -0.41866734 \end{pmatrix} \begin{pmatrix} 0.9781476 \\ -0.14701576 \\ -0.14701576 \end{pmatrix}$$

$$\hat{GS}_I = C^T \begin{pmatrix} 0 & 0 & -1 \\ 0 & -1 & 0 \\ -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 0.9781476 \\ -0.071960112 \\ 0.19506144 \end{pmatrix} = C^T \begin{pmatrix} -0.19506153 \\ +0.071960145 \\ -0.9781476 \end{pmatrix}$$

$$\hat{GS}_I = \begin{pmatrix} 0.46648762 & 0.87327045 & -0.14066990 \\ 0.36798215 & -0.33621705 & -0.86691827 \\ -0.80434972 & 0.35264260 & -0.47818902 \end{pmatrix} \begin{pmatrix} -0.19506153 \\ +0.071960145 \\ -0.9781476 \end{pmatrix} = \begin{pmatrix} +0.10944277 \\ 0.7520006 \\ 0.65001327 \end{pmatrix}$$

$$\alpha = \tan^{-1} (Y/X) = 81^\circ.719$$

$$\delta = \sin^{-1} (Z) = 40.^\circ 542$$

This indeed points the right tracker at the guide star.

## APPENDIX A

### MEASUREMENT OF MISALIGNMENTS (THE $T_{P,E}$ MATRIX)

The principle coordinate systems used in the IPS program are shown and identified in Figure A-1. In this particular figure, the baseplate of the OSP is shown as sitting on top of the IPS. This is merely to identify the various coordinate systems and their relation to each other. As mounted in the bay of the orbiter for the ASTRO-1 mission, the baseplate of the OSP is rotated 225 deg about the  $X_C$  axis, i.e., this is a positive 225 deg rotation in the C system and a negative 225 deg rotation in the B system. This is shown in Figure A-2. The systems attached to the OSP are rotated, i.e., the M, S, P, E systems. The systems B, C, and PAR are not rotated. In this mounted position, the P system is nominally aligned with the IPS gimbal system, C system, also called the Control Torque Actuator and Resolver system.

The measurements of the misalignments between the HUT telescope and the OSP were made on the ground at KSC. The actual measurements made were the misalignments between the HUT and the PAR system (Local Vertical, Local Horizontal) and between the OSP and the PAR system. Mathematical transformations are then employed to determine the misalignments between HUT and OSP.

The misalignments between the OSP and the PAR system are given as Pitch, Yaw and Roll from the PAR system to the OSP system; however, the signs of these (small) angles are given with respect to the IPS C system (rotated 180 deg about X from PAR system). These misalignments are shown (not to scale) in Figure A-3. The values are:

#### Misalignments of OSP

- 1) The angle up from the OSP LOS to cruciform reference (PAR) in Local Vertical, Local Horizontal is 232."6  $PITCH_{IPS} = P_1 = -0.^{\circ}064611$
- 2) The OSP LOS is 171."8 to the right of the PAR axis as viewed from the PAR  $YAW_{IPS} = Y_1 = 0.^{\circ}047722$
- 3) The OSP Z-axis is rolled 3373" from the PAR Z axis toward the PAR Y Axis.  $ROLL_{IPS} = R_1 = -0.^{\circ}93694$

#### Misalignment of HUT

The misalignments of HUT are measured the same way and illustrated also in Figure A-3. The values are

$$PITCH_{IPS} = P_2 = -118" = -0.^{\circ}032777$$

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$$YAW_{IPS} = Y_2 = -70'' = -0.^\circ 019444$$

$$ROLL_{IPS} = R_2 = -1587'' = -0.^\circ 440833$$

To get the misalignments between the HUT and the OSP then one could almost take the difference between the Pitch, Yaw, and Roll angles since they are small. The rigorous and correct way to do it however is as follows:

The rotation from the PAR to the HUT is given by

$$\bar{X}_{HUT} = (R_2)_X (Y_2)_Z (P_2)_Y \bar{X}_{PAR} \quad (A-1)$$

and the rotation from the PAR to the OSP is given by

$$\bar{X}_{OSP} = (R_1)_X (Y_1)_Z (P_1)_Y \bar{X}_{PAR} \quad (A-2)$$

To get the rotation matrix from the HUT to the OSP (the  $T_{P,E}$  matrix), we invert equation (A-1) or solve it for  $\bar{X}_{PAR}$  to get

$$\bar{X}_{PAR} = (P_2)_Y^T (Y_2)_Z^T (R_2)_X^T \bar{X}_{HUT} \quad (A-3)$$

Now substitute equation (A-3) for  $\bar{X}_{PAR}$  into equation (A-2) to get

$$\bar{X}_{OSP} = (R_1)_X (Y_1)_Z (P_1)_Y (P_2)_Y^T (Y_2)_Z^T (R_2)_X^T \bar{X}_{HUT} \quad (A-4)$$

This gives the transformation from the HUT to the OSP and, by definition, the resultant matrix is  $T_{P,E}$ ; i.e.,

$$T_{P,E} = (R_1)_X (Y_1)_Z (P_1)_Y (P_2)_Y^T (Y_2)_Z^T (R_2)_X^T \quad (A-5)$$

or

$$T_{P,E} = (R_1)_X (Y_1)_Z (P_1-P_2)_Y (Y_2)_Z^T (R_2)_X^T \quad (A-5')$$

There is an equivalent P, Y, R which will produce the same result as that of the matrix in equation (A-5). This equivalent set gives a  $T_{P,E}$  of

$$T_{P,E} = (R)_X (Y)_Z (P)_Y \quad (A-6)$$

or

$$T_{P,E} = \begin{pmatrix} \cos P \cos Y & \sin Y & -\sin P \cos Y \\ -\cos P \sin Y \cos R + \sin P \sin R & \cos Y \cos R & \sin P \sin Y \cos R + \cos P \sin R \\ \cos P \sin Y \sin R + \sin P \cos R & -\cos Y \sin R & -\sin P \sin Y \sin R + \cos P \cos R \end{pmatrix} \quad (A-6')$$

By putting the measured values of  $P_1$ ,  $Y_1$ ,  $R_1$  and  $P_2$ ,  $Y_2$ ,  $R_2$  into equation (A-5) and multiplying them out and then equating that matrix, element by element, to the matrix in equation (A-6) and then solving for the equivalent pitch, yaw, and roll one gets

$$P = -0.^\circ 032349838$$

$$Y = +0.^\circ 066919081 \quad (A-7)$$

$$R = -0.^\circ 49609996$$

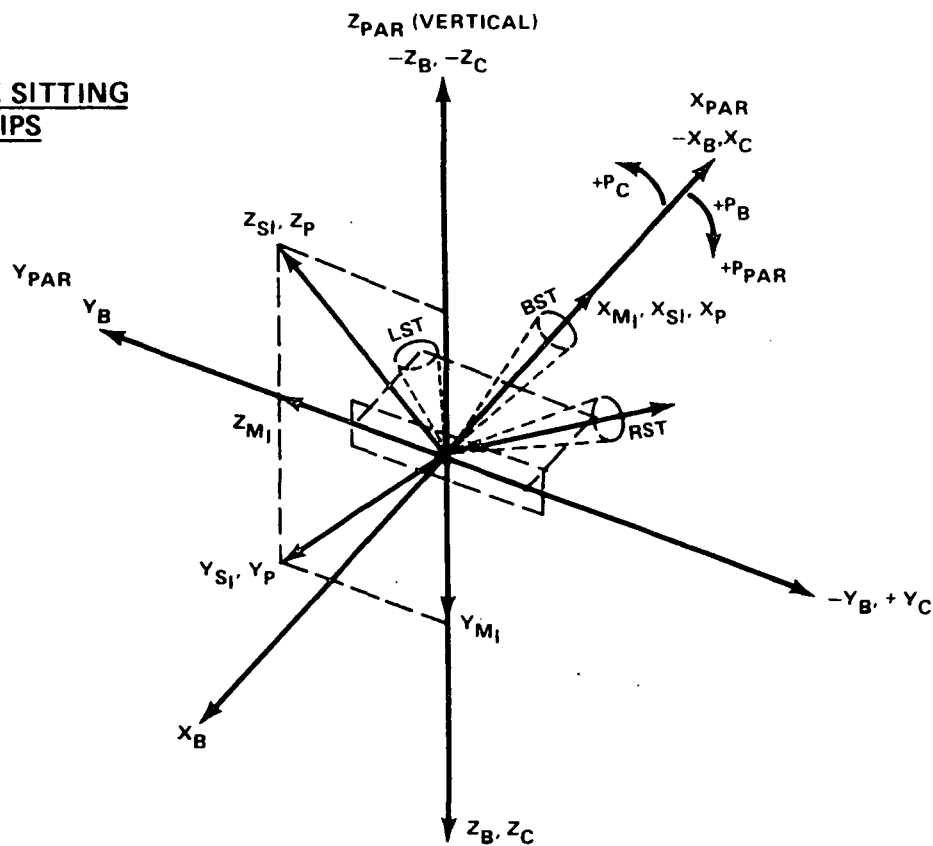
This set is nearly the same as one would get by simply differencing the two sets of individual values, but not quite. Putting these values into equation (A-6') one gets the following numerical results for the  $T_{P,E}$  matrix

$$T_{P,E} = \begin{pmatrix} 0.99999916 & 0.001167956 & +0.0005646101 \\ -0.001163024 & 0.99996183 & -0.00865913 \\ -0.000574702 & +0.00865846 & +0.99996285 \end{pmatrix} \quad (A-8)$$

The angles in equation (A-7) are the rotation angles required to rotate a coordinate system from the HUT position (experiment) to the OSP position (platform).



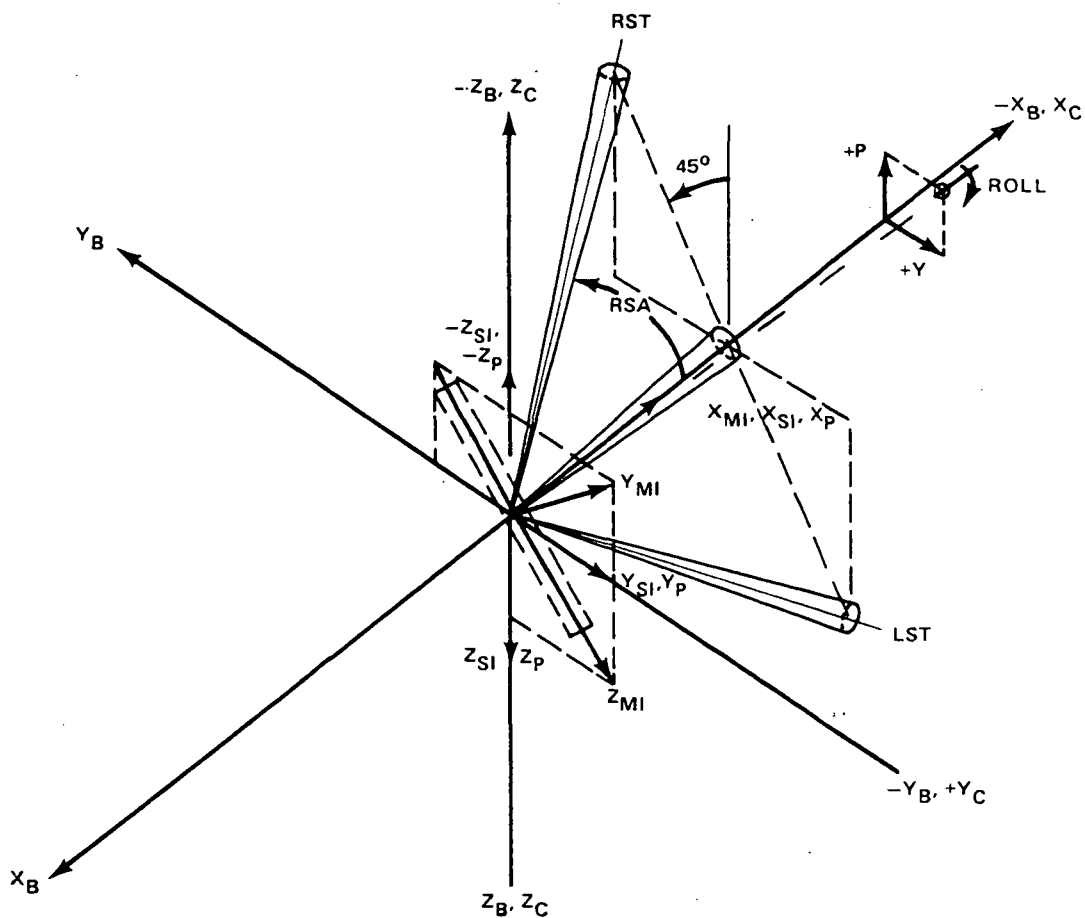
**BASEPLATE SITTING  
ON TOP OF IPS**



- B ORBITER BODY SYSTEM**
- C CONTROL TORQUE ACTUATOR & RESOLVER SYSTEM (180° ROTATION ABOUT Z FROM B SYSTEM)**
- M<sub>1</sub> OPTICAL SENSORS MEASUREMENT REFERENCE SYSTEM**
- S<sub>1</sub> AMA OPTICAL SENSORS REFERENCE SYSTEM (45° ROTATION ABOUT X FROM M SYSTEM)**
- P IPS PLATFORM FIXED COORDINATE SYSTEM (SAME AS S<sub>1</sub>)**
- E EXPERIMENT FIXED REFERENCE SYSTEM (SLIGHT DEVIATION FROM P SYSTEM)**
- PAR PAYLOAD ATTACHMENT RING SYSTEM (180° ROTATION ABOUT Y FROM B SYSTEM)  
(180° ROTATION ABOUT X FROM C SYSTEM)**

Figure A-1. Coordinate systems used for IPS.

BASEPLATE ROTATED 225°  
ABOUT X-AXIS FROM  
TOP POSITION



THE PLATFORM SYSTEM (P) IS NOMINALLY ALIGNED WITH THE  
GIMBAL SYSTEM (C).

RST - RIGHT SKEWED TRACKER  
RSA - RIGHT SKEWED ANGLE  
LST - LEFT SKEWED TRACKER  
LSA - LEFT SKEWED ANGLE

Figure A-2. Coordinate systems of IPS when it is in its stowed position.

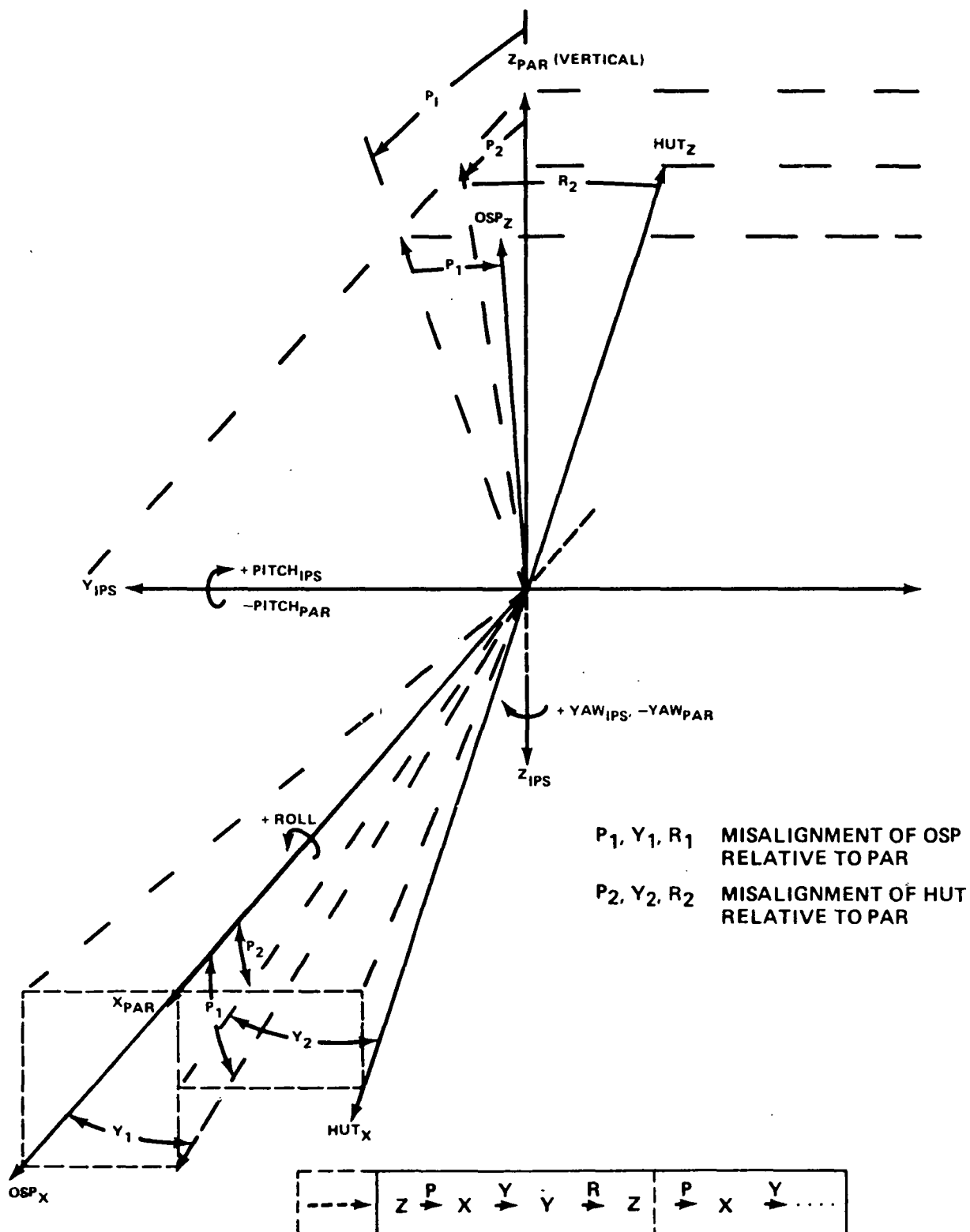


Figure A-3. Alignments of ISP and HUT relative to PAR system.

## APPENDIX B

### CALCULATING STAR TRACKER COUNT RATES

The count rate, CR, produced by a star of magnitude Mv appearing in the field-of-view (FOV) of a star tracker is given by the equation

$$CR = \frac{LC * e^{-EC * Mv}}{K} \quad (B-1)$$

LC is the leading "constant." EC is the exponential "constant," and K is the detection threshold constant. Although LC and EC are referred to loosely as constants, they are not constant in any sense of the word. They are dependent on the temperature of the star (spectral class) on the position of the star in star tracker FOV and each varies from one instrument to another. There are currently six star trackers in NASA inventory referred to as FM1, FM2, FM3, FM4, FM5, and FM6. On any given flight, three of these will be used on the IPS. Table B-1 gives the current calibrated values of EC and LC for each of these six instruments at three different stellar temperatures (3000°K, 6000°K, and 28,000°K) at both the center and edge of the field of view of each tracker. The table also lists the sources of the data. In addition to the center and edge values of these constants, there is also a combined value which is (or in some cases is close to) the geometric mean of the center and edge values. [If  $X_1$  and  $X_2$  are two numbers, their geometric mean is  $\sqrt{X_1 * X_2}$ .] Of the three "constants" in equation (B-1), only K, the threshold detection constant, seems to be truly constant. Its current value is given as 2.55 but that could be changed if new calibrations should be done on the trackers. [An earlier value of this constant was given as 2.38.]

Plots of the leading constant, LC, for each of the six instruments are given as a function of stellar temperature for the center of the FOV in Figure B-1 and the edge of the FOV in Figure B-2. There are measured values at only three temperatures, so the placement of French curves through these three points is somewhat arbitrary. It is unknown what the curves look like between 6,000°K and 28,000°K but the shapes shown in the plots look reasonable. Figures B-3 and B-4 show similar plots for the exponential constant, EC, for the center and edge of the FOV, respectively, for each instrument.

The temperature of a star determines its spectral class which is also shown along the abscissa of Figure B-1.

The temperature ranges of the spectral classes are somewhat provisory, but the one that will be used here for the purpose of determining star tracker count rates is:

<u>Spectral Class</u>	<u>Temperature (°K)</u>
O	>25,000
B	11,000 - 25,000
A	7,500 - 11,000
F	6,000 - 7,500
G	5,000 - 6,000
K	3,500 - 5,000
M	<3,500

The transition from one spectral class to another proceeds in 10 smaller steps called subclasses, i.e., Class G is subdivided into subclasses G0, G1, G2, ... G9, etc. The temperature ranges given above will be divided into 10 even steps for the subclasses for our purposes, i.e., G0 will represent the range 5900 to 6000°K, G1 the range 5800 to 5900°K, etc. The temperature of a star will then be assigned the mid-point of the range; i.e., a G2 star such as the Sun would cover the range 5700 to 5800°K and would be assigned the discrete temperature of 5750°K for purposes of calculating the "constants" in the count rate equations which have been shown in Table B-1 and Figures B1 through B4. All class O stars will be assigned the temperature of 28,000°K and class M stars the temperature of 3000°K, the two calibration values of the star trackers.

In order to get an accurate count rate estimate for any given star, it is necessary to be able to determine fairly accurately the constants LC and EC which go into the count rate equation (B-1). To do this, it is necessary to fit a function to the curves shown in Figures B-1 through B-4. If such a function is in hand, then by knowing which star tracker is being used, the temperature of the star being observed and its position in the FOV of the tracker, one can determine the expected count rate.

After some experimentation, it has been determined that a function of the form  $T/(a + bT + cT^2)$  will fit both the leading constant and the exponential constant very well. Using this form, the leading constant, LC, would be

$$LC = T/(a+bT+cT^2) \quad (B-2)$$

where a, b, and c are coefficients to be determined from the calibration data given in Table B-1. For purposes of determining the coefficients, equation (B-2) is rewritten in the form

$$a + bT = cT^2 = T/LC$$

Writing this three times for the three separate temperatures and writing the result in matrix form gives

$$\begin{pmatrix} 1 & T_1 & T_1^2 \\ 1 & T_2 & T_2^2 \\ 1 & T_3 & T_3^2 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} T_1/LC1 \\ T_2/LC2 \\ T_3/LC3 \end{pmatrix} \quad (B-3)$$

or compactly as

$$M C = T/LC \quad (B-3')$$

solving for the coefficients, C, one gets

$$C = M^{-1} (T/LC) \quad (B-4)$$

The matrix M defined by equation (B-3) will be a fixed matrix since the three temperatures at which the constants are given are all fixed (3000°K, 6,000°K, and 28,000°K). This matrix will be the same for all trackers, for both the edge and center of the FOV and also the same for the exponential constant, EC. The coefficients will vary from case to case only because the "vector" on the right side of equation (B-3) varies.

The matrix of the form which M has is called a Vandemonde matrix. Its determinant is

$$\det M = (T_3 - T_2) (T_3 - T_1) (T_2 - T_1)$$

and  $M^{-1}$  is

$$M^{-1} = \frac{1}{\det M} \begin{pmatrix} T_2 T_3 (T_3 - T_2) & -T_1 T_3 (T_3 - T_1) & T_1 T_2 (T_2 - T_1) \\ -(T_2 + T_3) (T_3 - T_2) & (T_1 + T_3) (T_3 - T_1) & -(T_1 + T_2) (T_2 - T_1) \\ (T_3 - T_2) & -1 \cdot (T_3 - T_1) & (T_2 - T_1) \end{pmatrix} \quad (B-6)$$

Note that  $M^{-1}$  is a function only of the three temperatures at which calibrations were done. It is not a function of the particular instrument being used, the magnitude of the star in the FOV, or the position of the star in the FOV. Therefore, for three fixed temperatures,  $M^{-1}$  will be a constant matrix for all trackers.

For the three listed temperatures,  $\det M = 1.65 \times 10^{12}$  and

$$M^{-1} = \begin{pmatrix} 56/25 & -14/11 & 18/550 \\ -34/75 \times 10^{-3} & 31/66 \times 10^{-3} & -9/550 \times 10^{-3} \\ 1/75 \times 10^{-6} & 1/66 \times 10^{-6} & 1/550 \times 10^{-6} \end{pmatrix}$$

In addition to being a function of temperature, the leading constant is also a function of the distance of the star from the center of the FOV of the tracker.

At the center of the FOV, the data for each tracker in the documents listed on Table B-1 gives a leading constant, LC, for each of the calibration temperatures, i.e.,  $LC_1$ ,  $LC_2$ ,  $LC_3$ . This can be substituted into equation (B-3) to get the set of constants,  $C_i$ . With these, equation (B-2) can be used to evaluate the LC for any temperature, not just one of the three calibrated values. This can be repeated for the edge of the FOV.

With these two values in hand, i.e., a leading constant for the center of the FOV,  $LC_C$ , and a leading constant for the edge of the FOV,  $LC_E$  (for a fixed temperature), and assuming the leading constant to be a linear function of the distance from the center, one gets the leading constant at any distance from the center,  $LC_d$  to be

$$LC_{dT} = LC_{CT} + S_T * d \quad (B-7)$$

where

$$S_T = (LC_{ET} - LC_{CT})/D \text{ (Slope)} \quad (B-8)$$

$LC_{CT}$  = leading constant at center of FOV at temperature T

$LC_{ET}$  = leading constant at edge of FOV at temperature T

$LC_{dT}$  = leading constant at distance d from center of FOV

D = total distance from center to edge ( $\approx 1^\circ.1$ )

d = instantaneous distance at which LC is desired

T = temperature at which all constants are evaluated .

Combining equations (B-7) and (B-8) gives

$$LD_{dT} = LC_{CT} + (LC_{ET} - LC_{CT}) * (d/D)$$

$$LC_{dT} = LC_{CT} (1 - d/D) + LC_{ET} * d/D \quad . \quad (B-9)$$

The exponential constant can be treated the same as the leading constant in all respects when fitting it to temperature and distance from the center of the FOV of the star tracker, i.e., a form like equation (B-2) will fit it and the coefficients can be determined by equation (B-4). Also an equation like (B-9) will give its dependence on distance from the center of the FOV.

FM5 is taken as an example: At the center of the FOV is

$$T1/LC1 = \frac{3,000}{53,249} \quad T2/LC2 = \frac{6,000}{73,896} \quad T3/LC3 = \frac{28,000}{69,364}$$

The coefficients in equation (B-2) will be

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 56/25 & -14/11 & 18/550 \\ -34/75 \times 10^{-3} & 31/66 \times 10^{-3} & -9/550 \times 10^{-3} \\ 1/75 \times 10^{-6} & -1/66 \times 10^{-6} & 1/550 \times 10^{-6} \end{pmatrix} \begin{pmatrix} 5.63390 \times 10^{-2} \\ 8.11951 \times 10^{-2} \\ 0.40366 \end{pmatrix} = \begin{pmatrix} 3.6071 \times 10^{-2} \\ 5.9912 \times 10^{-6} \\ 2.548 \times 10^{-10} \end{pmatrix}$$

So

$$LC = T / (3.6071155 \times 10^{-2} + 5.9972806 \times 10^{-6} T + 2.548987 \times 10^{-10} T^2)$$

At a few points of temperature LC is calculated from this equation.

<u>Temperature (°K)</u>	<u>LC Center</u>
*3000	53249
*6000	73896
10,000	82322
15,000	81836
20,000	77562
*28,000	69364

The starred temperature values are the calibrated values and the calculated value of LC agrees exactly with them as it should since they were used to fit the curve.



These values are plotted in Figure B-5.

For FM5 at the edge of the FOV, one has

$$\begin{array}{ccc} T_1/LC1 = \frac{3,000}{59,666} & T_2/LC2 = \frac{6,000}{79,590} & T_3/LC3 = \frac{28,000}{72,477} \end{array}$$

The coefficients for equation (B-2) will be

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 56/25 & -14/11 & 18/550 \\ -34/75 \times 10^{-3} & 31/66 \times 10^{-3} & -9/550 \times 10^{-3} \\ 1/75 \times 10^{-6} & -1/66 \times 10^{-6} & 1/550 \times 10^{-6} \end{pmatrix} \begin{pmatrix} 0.050619 \\ 0.075386 \\ 0.386329 \end{pmatrix} = \begin{pmatrix} 0.03008 \\ 6.1396 \times 10^{-6} \\ 2.3512 \times 10^{-10} \end{pmatrix}$$

$$LC_{\text{edge}} = T / (3.0084341 \times 10^{-2} + 6.1395981 \times 10^{-6} T + 2.351229 \times 10^{-10} T^2)$$

At few points of temperature, the following is calculated:

<u>Temperature (°K)</u>	<u>LC Edge</u>
3,000*	59,266
5,000	75,007
6,000*	79,590
10,000	86,962
15,000	85,675
20,000	80,996
28,000*	72,477

These values are also plotted in Figure B-5.

For a point midway between the center and the edge of the FOV, equation (B-9) would give a value exactly halfway between the two curves shown in Figure B-5.

For the exponential constant, EC, at the center of the FOV for FM5, one gets

$$T_1/EC_1 = 3,000/-0.909 \quad T_2/EC_2 = 6000/-0.927 \quad T_3/EC_3 = 28,000/-0.899$$

and the coefficients for an equation of the type (B-2) will be

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 56/25 & -14/11 & 18/550 \\ -34/75 \times 10^{-3} & 31/66 \times 10^{-3} & -9/550 \times 10^{-3} \\ 1/75 \times 10^{-6} & -1/66 \times 10^{-6} & 1/550 \times 10^{-6} \end{pmatrix} \begin{pmatrix} -3300.33 \\ -6472.4919 \\ -31145.717 \end{pmatrix} = \begin{pmatrix} -174.33661 \\ -1.034304 \\ -2.565 \times 10^{-6} \end{pmatrix}$$

$$EC_{\text{Center}} = T / (-174.33661 - 1.034304T - 2.5649172 \times 10^{-6} T^2) \quad .$$

At a few points of temperature, the following is calculated:

<u>Temperature (°K)</u>	<u>EC Center</u>
3,000*	-0.909
5,000	-0.924
6,000*	-0.927
10,000	-0.928
15,000	-0.922
20,000	-0.914
28,000*	-0.890

This data is also plotted on Figure B-5.

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TABLE B-1. VALUES OF THE LEADING CONSTANT (LC) AND EXPONENTIAL CONSTANT (EC) AS A FUNCTION OF STELLAR TEMPERATURE AT THE CENTER AND EDGE OF THE FOV OF EACH OF THE SIX STAR TRACKERS

<u>INSTRUMENT</u>		<u>3000°K</u>		<u>6000°K</u>		<u>28,000°K</u>	
		<u>LC</u>	<u>EC</u>	<u>LC</u>	<u>EC</u>	<u>LC</u>	<u>EC</u>
FM1	CENTER	33,665	-0.920	36,930	-0.920	41,321	-0.920
	EDGE	26,200	-0.846	31,032	-0.846	35,257	-0.846
	COMBINED	29,699	-0.883	33,861	-0.883	38,181	-0.883
FM2	CENTER	36,687	-0.887	41,968	-0.887	47,357	-0.887
	EDGE	41,233	-0.887	46,227	-0.887	52,266	-0.887
	COMBINED	38,894	-0.887	44,097	-0.887	49,811	-0.887
FM3	CENTER	45,100	-0.909	53,094	-0.909	61,302	-0.909
	EDGE	47,475	-0.921	61,808	-0.921	70,251	-0.921
	COMBINED	46,272	-0.915	57,359	-0.915	65,687	-0.915
FM4	CENTER	34,456	-0.912	45,696	-0.924	50,602	-0.937
	EDGE	39,838	-0.920	54,986	-0.945	56,265	-0.926
	COMBINED	37,328	-0.918	50,602	-0.937	53,446	-0.931
FM5	CENTER	53,249	-0.909	73,896	-0.927	69,364	-0.899
	EDGE	59,266	-0.913	79,590	-0.924	72,477	-0.890
	COMBINED	56,135	-0.910	76,697	-0.925	70,798	-0.893
FM6	CENTER	27,649	-0.899	33,397	-0.878	38,125	-0.903
	EDGE	31,963	-0.913	37,399	-0.882	41,836	-0.903
	COMBINED	29,582	-0.905	35,833	-0.883	40,611	-0.907

DATA SOURCES:

FM1, FM2, FM3 - IPS-DS-MH006, 7, 8 (JULY 19, 1982)  
 FM1, FM2, FM5 - IPS.SOD.UM.0008, 9, 4 (NOV. 21, 1985)  
 FM4, FM5, FM6 - IPS-DS-TN-506 (NOV. 16, 1984)

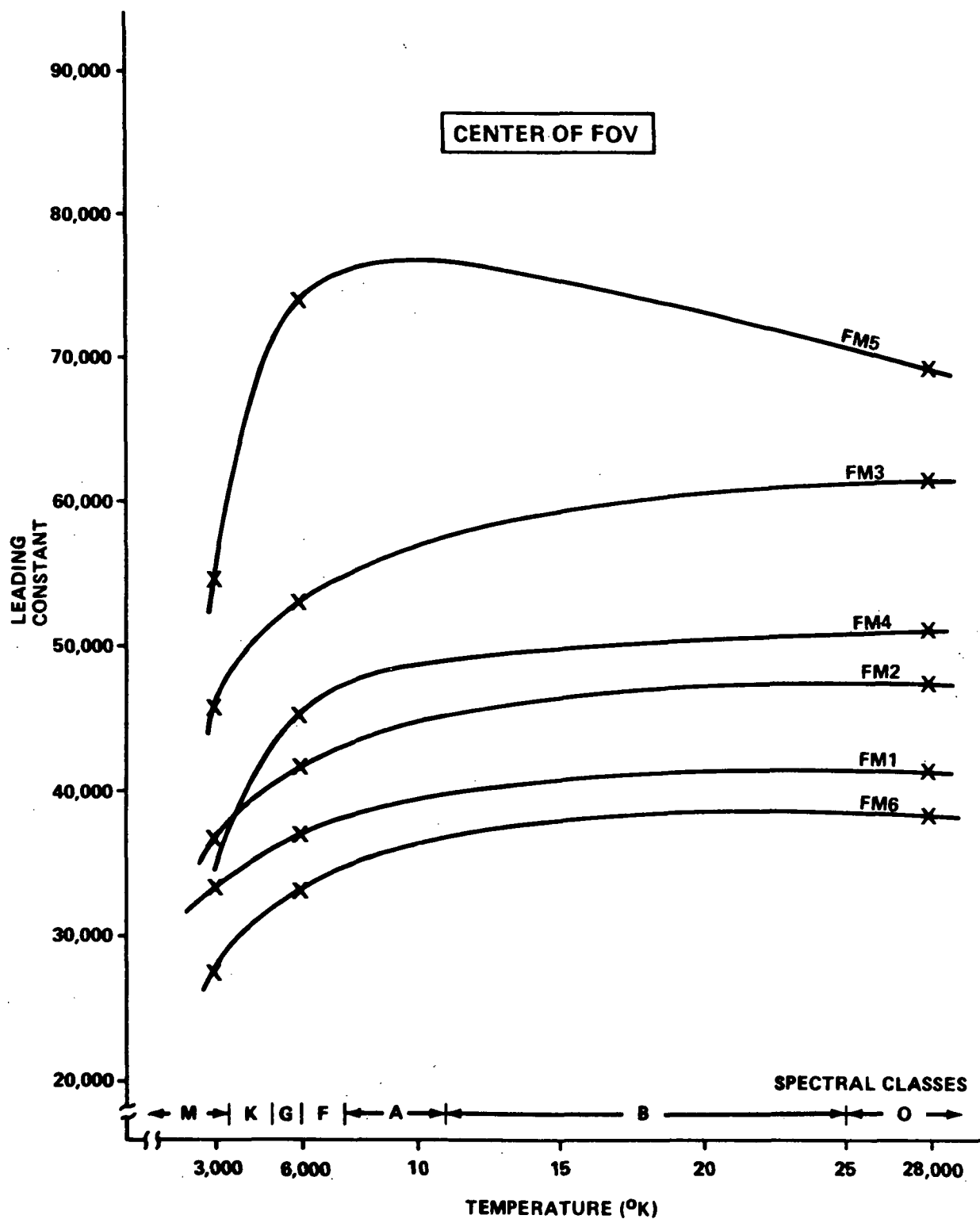


Figure B-1. Temperature response of the leading constant in the star tracker count rate equation for each of the six star trackers in the center of the FOV.

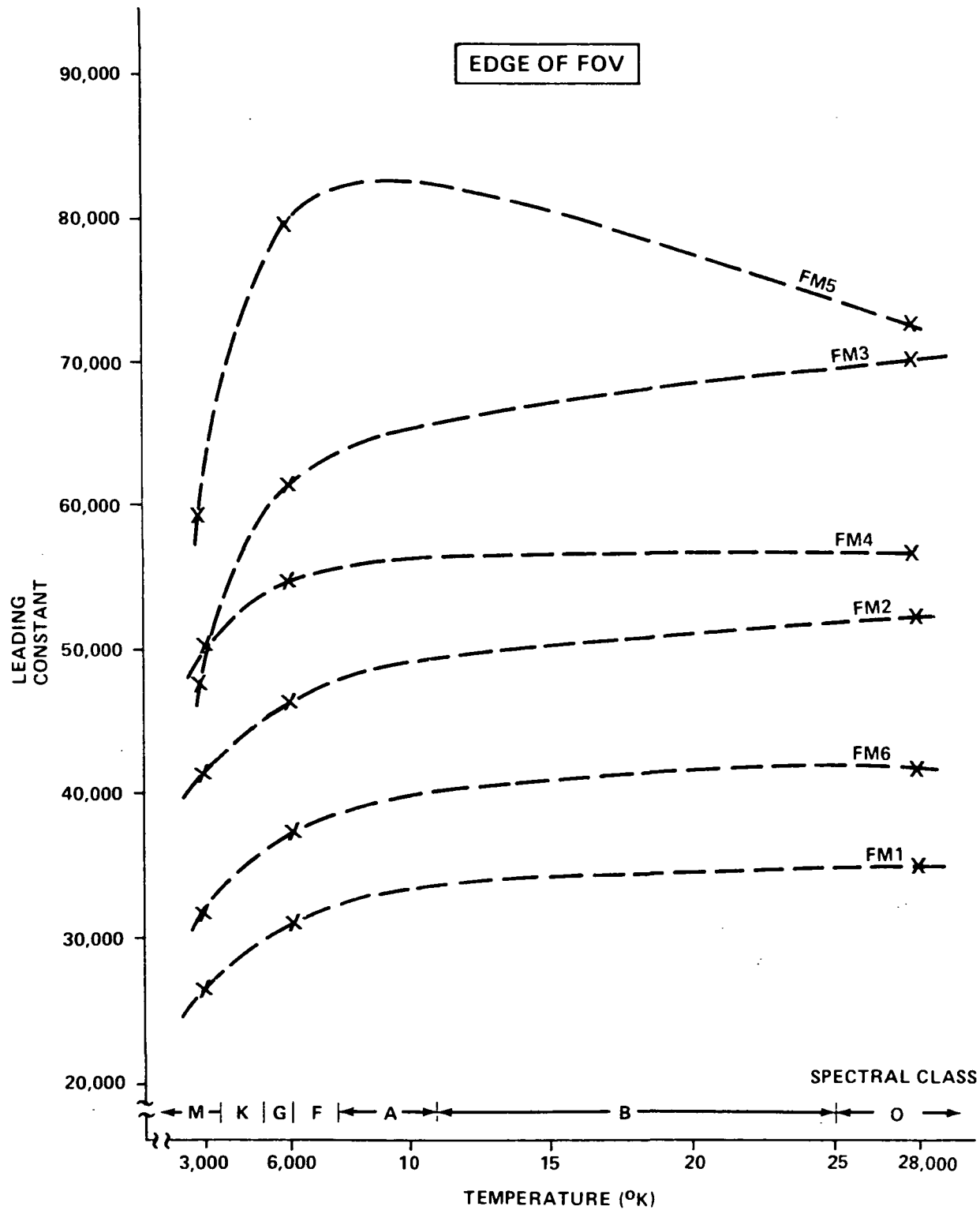


Figure B-2. Temperature response of the leading constant in the star tracker count rate equation for each of the six star trackers on the edge of the FOV.

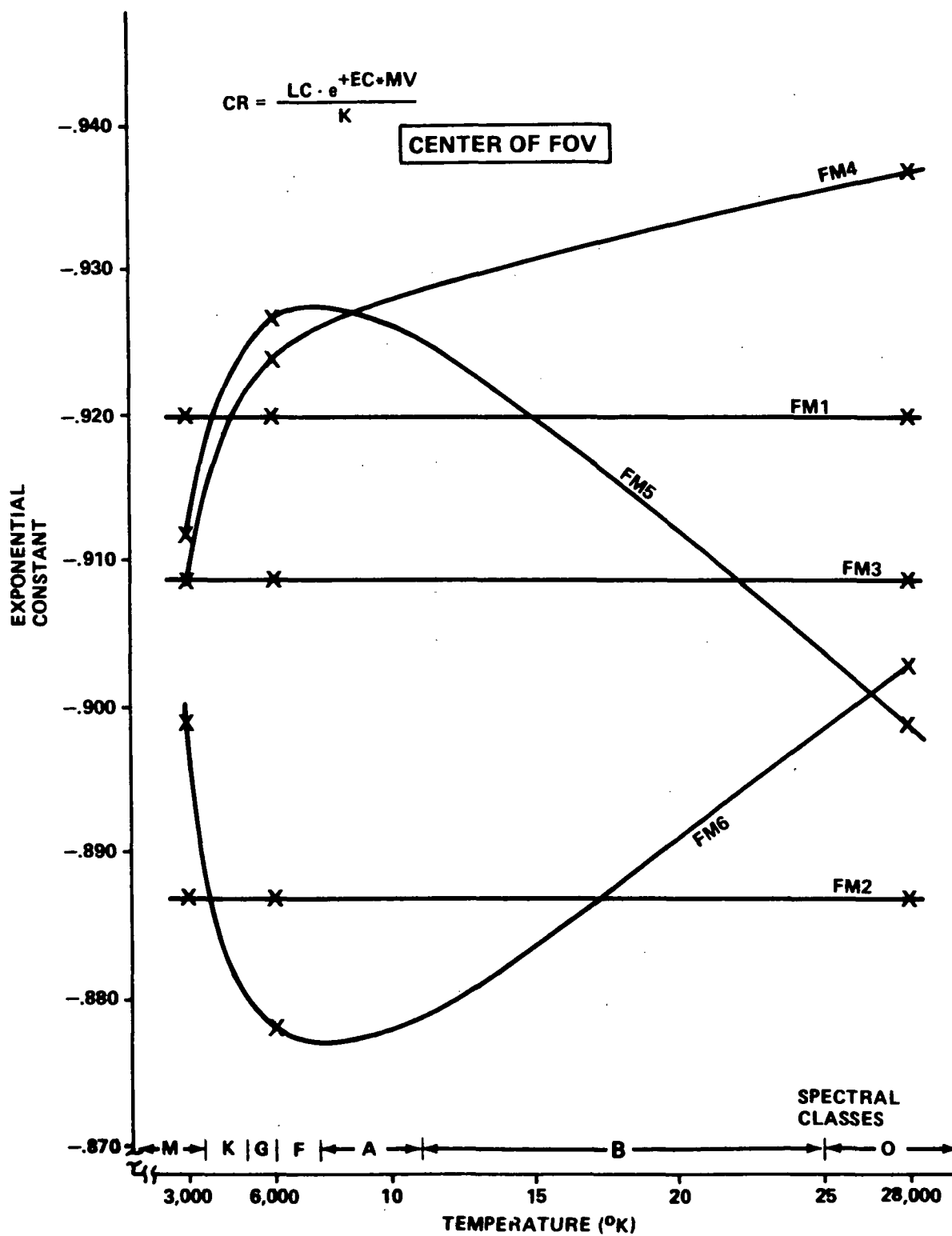


Figure B-3. Temperature response of the exponential constant in the star tracker count rate equation for each of the six star trackers in the center of the FOV.

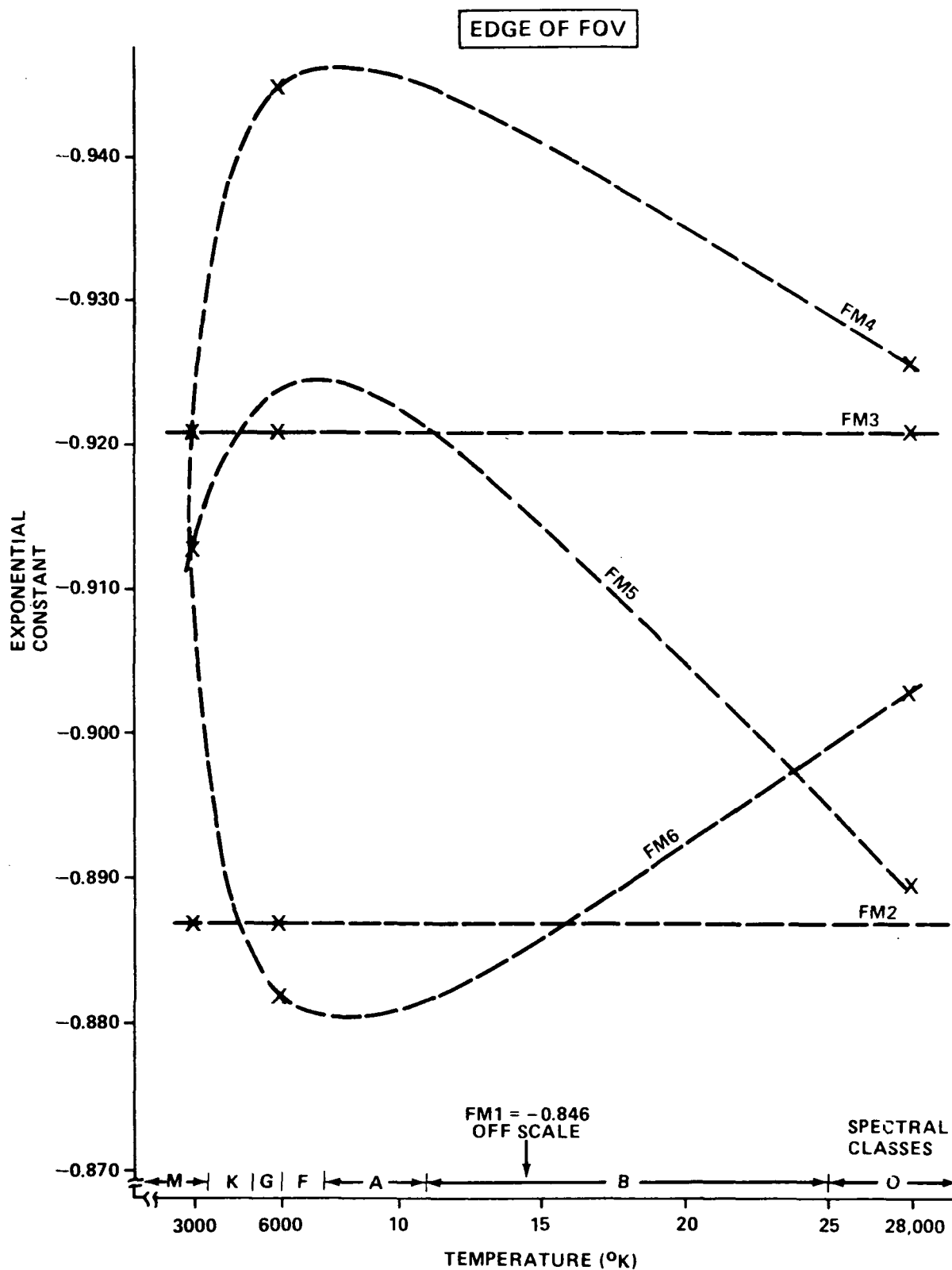


Figure B-4. Temperature response of the exponential constant in the star tracker count rate equation for each of the six star trackers on the edge of the FOV.

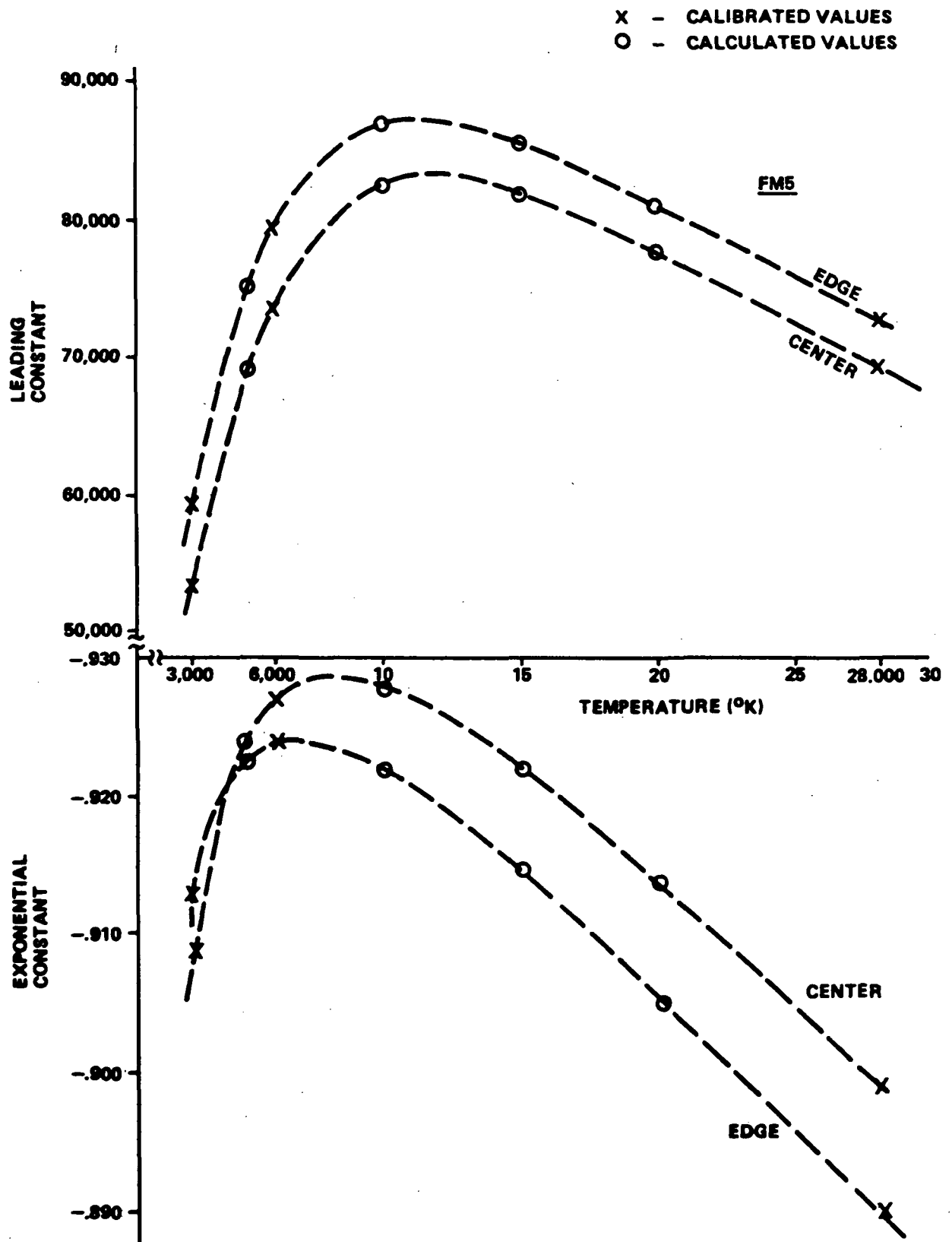


Figure B-5. Curve fits of leading constants and exponential constants to calibrated data for FM5 using functions of the form:

$$LC = T / (a + bT + cT^2).$$



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## APPENDIX C

### CONVERTING CENTRAL ANGLE SUBTENDED BY SKEWED STAR TRACKER FOV INTO A ROLL ANGLE ABOUT IPS BORESIGHT

Half of one side of the FOV of the star tracker, as shown in Figure C-1, subtends a central angle (projected on the celestial sphere) of 1 deg. Napier's rule applied to the right spherical triangle ABC in Figure C-1 gives

$$\cos u = \cos 11^\circ \cos 1^\circ$$

$$u = 11.^\circ 0.448$$

Then the law of cosines applied to the triangle ABC gives

$$\cos 1^\circ = \cos 11^\circ \cos 11.^\circ 0.448 + \sin 11^\circ \sin 11.^\circ 0.448 \cos \text{ROLL}$$

or

$$\cos \text{ROLL} = \frac{\cos 1^\circ - \cos 11^\circ \cos 11.^\circ 0.448}{\sin 11^\circ \sin 11.^\circ 0.448}$$

or

$$\text{ROLL} = 5.^\circ 22683$$

If the central angle of the edge of the FOV is increased to 2.°85, as required by the uniqueness criteria, then  $u = 11.^\circ 3588$  and  $\text{ROLL} = 14.^\circ 623$ .

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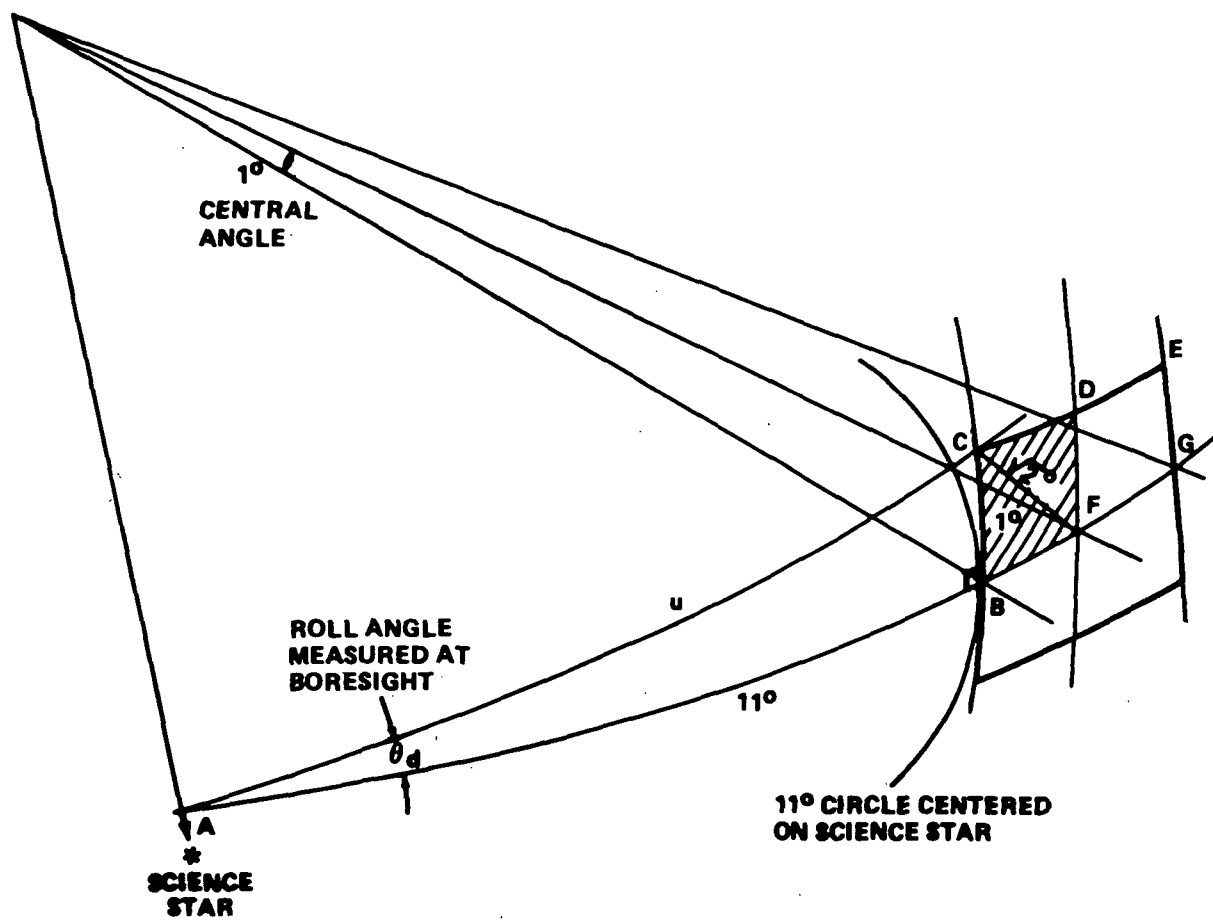


Figure C-1. Detailed view of square  $2^\circ \times 2^\circ$  FOV projected onto spherical surface.

## APPENDIX D

### COMPUTER CODE

Several pieces of software have been written to do the general job of guide star selection and objective loads generation for an IPS stellar mission. The interaction by data transfer through computer files with several other pieces of existing MIPS software. All of this guide star software resides under the umbrella name of GSOLP (Guide Star Objective Load Program). Individual pieces of software under this umbrella name are GSSEP (Guide Star SElection Program), GSCUP (Guide Star Catalog Utility Program), GIMOP (GIMbal angle Optimization Program), OBJUP (OBJective load Utility Program), OBGEN (OBJective load GENerator program). The linkage or interfaces between these programs and others in the MIPS system are shown in Figure D-1.

The general task of GSSEP is outlined in Figure 9 of this document. It takes a set of science stars and then searches the SKYMAP catalog in the vicinity of that science star to find suitable guide stars. GSCUP then takes these guide stars and loads them into a data base suitable for further processing. It also does plots and tabulations from this data base. OBJUP writes the objective loads in ASCII format. OBGEN transforms the ASCII format into a binary from which can be directly loaded onto the onboard MMU. GIMOP takes the orbiter attitude (P, Y, R) and the objective load roll angle and computes the IPS Gimbal angles (EL, XL, RL). Section IX of this document gives the theory behind the operation of GIMOP and GIMBAL.

Figure D-2 shows a more detailed flow of the guide star programs with the files that need them and the files that they output. A complete list of all of the files and their types are shown in Table D-1. The format of each file is shown in Tables D-2 through D-12.

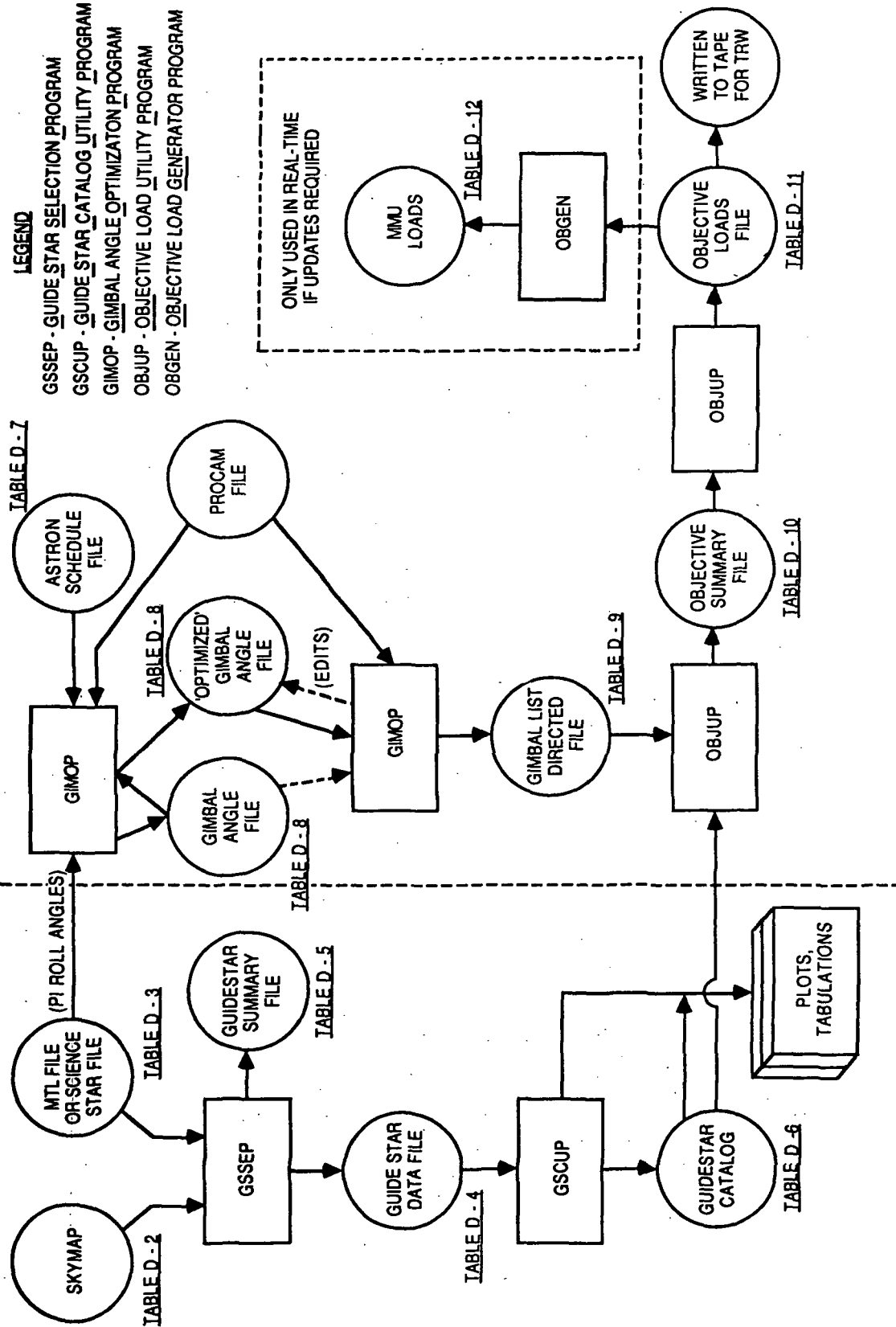


Figure D-1. Program module flow and file interaction for the ASTRO guide star selection program GSOLP (Guide Star Objective Load Program).

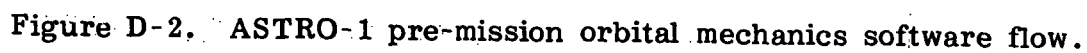


TABLE D-1. LIST OF FILES AND THEIR TYPES

<u>File</u>	<u>TYPE</u>	<u>FORMAT</u>	<u>COMMAND TO EXAMINE FILE</u>
SKYMAP	Direct Access	Table D-2	Run Scatgen Option 10, sub option 4
MTL	Sequential ASC II	Table D-3	Type FILENAME.TYPE
Guidestar Data File	Direct Access	Table D-4	Run GSSEP/Option 5
Guidestar Summary File	Sequential Binary	Table D-5	Run GSSEP/Option 4
Guidestar Catalog	Direct Access	Table D-6	Run GSCUP-Options 3,4,
ASTRON Schedule	MIPS ON/OFF	Table D-7	Run TARGEN - Option 9
Gimbal Angle	Sequential ASC II	Table D-8	Type FILENAME.TYPE
Gimbal	MIPS List Directed	Table D-9	Run TABUL
Objective Loads Summary	Direct Access	Table D-10	Run OBJUP, Option 4 for Summary (Part of File)
Objective Loads	Sequential ASC II	Table D-11	Type FILENAME.TYPE
MMU Loads	Unformatted Direct Access	Table D-12	None Possible

NOTE: The format of every file shown on Figure D-1 is shown in the following Tables except the PROCAM file. Its format can be found in the PROCAM document.

# TABLE D-2. SKYMAP CATALOG FILE FORMAT

## SKYMAP V3.0 VAX Data Base Description

(SKYMAP V3.0)

MIPS 4, DISK\$PMISB: [SKYMAP] SKYMAP.V30;1

<u>Master Catalog Word</u>	<u>VAX Catalog Word</u>	<u>Byte</u>	<u>Type</u>	<u>Description</u>
-	1	1	I	Next higher RA index number
-	2	5	I	Next higher DEC index number
-	3	9	I	Next lower RA index number
-	4	13	I	Next lower DEC index number
2	5	17	I	SKYMAP number
8	6	21	A	Star name
9	7	25	A	Star Name
10	8	29	A	Star Name
11	9	33	A	Star Name
12	10	37	A	Star Name
13	11	41	R	Right ascension, standard epoch
14	12	45	R	Declination, standard epoch
15	13	49	R	Error in standard epoch positio
25	14	53	R	Proper motion in right ascensio
26	15	57	R	Proper motion in declination
27	16	61	R	Precession in right ascension
28	17	65	R	Precession in declination
31	18	69	R	U magnitude
33	19	73	R	B magnitude
34	20	77	R	V magnitude
35	21	81	I	B, V magnitude derivation flag
36	22	85	R	Photovisual magnitude
37	23	89	R	Photographic magnitude
38	24	93	I	Photovisual-photographic presence flag
42	25	97	I	Spectral class
43	26	101	I	Luminosity class
44	27	105	I	Peculiarity code
45	28	109	I	Spectral type source flag
70	29	113	I	Variability type code
72	30	117	R	Bright/dim magnitude difference
73	31	121	I	Variable magnitude type flag
76	32	125	R	Separation, multiple star
77	33	129	R	Difference in brightness of 76
79	34	133	R	Distance to catalogue nearest neighbor



TABLE D-3. MTL FILE

<u>Word</u>	<u>Description</u>	<u>Data Type</u>	<u>Units</u>
1	Target Name 1	C*8	-
2	Target ID	C*8	-
3	Target Name 2	C*12	-
4	Class. Subclass	R*4	-
5	Priority	I*4	-
6	Length of Observation	I*4	Seconds
7	*Flag for Continuous or Non-continuous Observation	I*4	-
8	**Day, Night or Combination Type Target	I*4	-
9	Target Right Ascension (M50)	R*4	Degrees
10	Target Declination (M50)	R*4	Degrees
11	HUT desired Slit Position Angle (+Y) (or Celestial Roll)	R*4	Degrees

\* 1 = Continuous Observation, 0 = Observation can be broken up

\*\* 1 = Night Target

2 = Day Target

3 = SAA Target

4 = Day to Night Target

5 = Night to Day Target

TABLE D-4. GUIDESTAR DATA FILE FORMAT

This file is dimensioned 2010 words per science star and one can put as many science stars on it as desired.

<u>Word #</u>	<u>Description</u>	<u>Type</u>	<u>Units</u>
1	Science Star Number (Sequence #)	I*4	-
2	Science Star ID (from COO file)	C*4	-
3	Science Star ID	C*4	-
4	Science Star RA (M1950)	R*4	Deg.
5	Science Star DEC (M1950)	R*4	Deg.
6	Science Star RA (M2000)	R*4	Deg.
7	Science Star DEC (M2000)	R*4	Deg.
8	MODE (1-IDOP, 2-IDIN, 3-OSPCAL)	I*4	-
9	No. of guidestars found in Annulus	I*4	-
10	No. of guidestars found in Boresight	I*4	-
11	1st guidestar location on SKYMAP	I*4	-
12	1st guidestar position (1=Boresight, 2=Annulus)	I*4	-
13	2nd guidestar location on SKYMAP	I*4	-
14	2nd guidestar position (1=Boresight, 2=Annulus)	I*4	-
2009	1000th guidestar location on SKYMAP	I*4	-
2010	1000th guidestar position (1=boresight, 2= Annulus)	I*4	-

TABLE D-5. GUIDESTAR SUMMARY FILE FORMAT

<u>Word No.</u>	<u>Description</u>	<u>Type</u>	<u>Units</u>
1	Science Star Number	I*4	-
2	Science Star ID	C*4	-
3	Science Star ID	C*4	-
4	Science Star RA (M1950)	R*4	Deg.
5	Science Star DEC (M1950)	R*4	Deg.
6	NPA - Total number of stars found during search of SKYMAP catalog in annulus region of Science Star	I*4	-
7	NBA - Total number of stars found during search of SKYMAP catalog in boresight region of Science Star	I*4	-
8	NCA - Total number of stars from annulus region which passed magnitude, variability and POS. ERR tests	I*4	-
10	NSA - Total number of stars from (8) which passed uniqueness tests; i.e., actual potential annulus; guidestars	I*4	-
11	NSB - Total number of stars from (9) which passed uniqueness tests; i.e., actual potential boresight guidestars	I*4	-
12	Computer time required to find these guidestars	R*4	Sec.
13	Mode (1-IDOP, 2-IDIN, 3-OSPCAL	I*4	-

TABLE D-6. GUIDESTAR CATALOG FILE FORMAT

The format of the guidestar catalog (12 words/record) is as follows:

Record 1 - Header Record	<u>Format</u>
Word 1 - Next available record on guidestar catalog	I*4
Word 2 - Number of science stars on catalog	I*4
3-7 - Date & Time Catalog was created	5(C*4)
8-12 - Date & Time Catalog was revised	5(C*4)
Records 2-68- Location of science stars on catalog	
Word 1 - Location of data for first science target	I*4
Word 804 - Location of data for first 804th science target	I*4

Records 69 and 70 contain the data for the 1st science target.

After these two records, there will be a number of records equal to the number of guide stars available for that science star (or IDIN star) up to but not exceeding 500 where each of these records contain 12 words of data about the guide star; for example, if there were 100 guide stars then there would be 100 records making a total of 170 records to this point.

The next two records would then contain the data for the 2nd science target; i.e., in this example, records 171 and 172. Following these again would be records of data for each guide star for this science star, etc. until all science stars were accomodated.

The formats for the records for the science stars and for the guide stars are shown below.

TABLE D-6. (Continued)

## Guidestar Catalog File Format for Records 69 &amp; 70 (Science Star Data)

<u>Word #</u>	<u>IDOP MODE</u> <u>Description</u>	<u>IDIN MODE</u> <u>Description</u>	<u>Type</u>	<u>Units</u>
1	Star Number	Star Number	I*4	-
2	Science Star ID	Star ID	C*4	-
3	Science Star ID	Star ID	C*4	-
4	Science Star RA (M50)	IDIN Star RA (M50)	R*4	Deg.
5	Science Star DEC (M50)	IDIN Star DEC (M50)	R*4	Deg.
6	Science Star Name		C*4	-
7	Science Star Name		C*4	-
8	Science Star Class Subclass		R*4	-
9	Science Star Priority		I*4	-
10	Science Star Observing Time		I*4	Sec.
11	Viewing Flag for Continuous or non-continuous observation		I*4	
12	Type Target (Day, Night, or combination)		I*4	
1	HUT Slit Position Angle	IDIN Star Spectral Class	R*4(I*4)	Deg
2	-	IDIN Star Visual Magnitude	(R*4)	
3	Science Star RA (M2000)	IDIN Star RA (M2000)	R*4	Deg.
4	Science Star DEC (M2000)	IDIN Star Dec (M2000)	R*4	Deg.
5	Total No. Guide Stars	Total No. Guide Stars	I*4	
6	No. Guide Stars in Annulus	No. Guidestars in Annulus	I*4	
7	No. Guide Stars in Boresight	No. Guidestars in Boresight		
8	IPS Operational Mode: 1-IDOP, 2-IDIN, 3=OSPCAL		I*4	
9			C*4	
10	Date & Time		C*4	
11	Target Written		C*4	
12			C*4	

TABLE D-6. (Concluded)

Format for Record #71, The First Guide Star for the First Science Star

<u>Word #</u>		<u>Type</u>	<u>Units</u>
1	Guide Star Right Ascension (M-2000)	R*4	Deg.
2	Guide Star Declination (M-2000)	R*4	Deg.
3	Position Angle	R*4	Deg.
4	Angular distance between Guide Star & Science Star	R*4	Deg.
5	Guide Star Visual Magnitude	R*4	
6	Guide Star Ultra-Violet magnitude	R*4	
7	Guide Star Blue Magnitude	R*4	
8	Guide Star Galactic Longitude	R*4	Deg.
9	Guide Star Galactic Latitude	R*4	Deg.
10	Guide Star SKYMAP Number	I*4	
11	Guide Star Spectral Class	I*4	
12	Guide Star Position (1=Boresight, 2=Annulus)	I*4	

The following records for each guide star have, of course, the same format of words as that shown above; i.e., Record #72 will be identified to record #71 it will be for the second guide star for the first science star, etc. This continues until all guide stars for the first science star have been accommodated.

Following this, the next two records will be identical in content to records #70 and #71 except they will be for the second science star, etc.

TABLE D-7. ASTRON SCHEDULE FILE FORMAT

This is a MIPS ON/OFF file. It consists of Header Records, Subject Records and Data Records.

#### Header Records

There are 10 header records which currently contain only; (1) the number of subjects on the file and (2) the number of data records on the file.

#### Subject Records

There are two types of subjects on this file, miscellaneous and celestial target. The miscellaneous subjects contain only the subject name and there are currently 10 of these, although this could be changed in the future. The current 10 (each limited to 8 characters ) are:

1. Handover
2. Idle Time
3. IPS SLEW
4. WTERDUM
5. Y TIME (includes time for IDOP)
6. Z TIME
7. GYROCAL
8. IDIN
9. OSPCAL
10. VEHMNR

The celestial target records contain the target name (8 characters), target right ascension (in degrees) and target declination (in degrees). There are as many of these records as there are targets. This can vary according to the schedule being run. It will probably exceed 200 for most timelines.

#### Data Records

The data records contain the subject name (from the subject records above) and the on-time and off-time for each time that particular subject is scheduled during the mission.

TABLE D-8. GIMBAL ANGLE FILE FORMAT

Gimbal Angle File Format

<u>Word #</u>	<u>Description</u>	<u>Data Type</u>	<u>Units</u>
1	Mission Elapsed Time	R*4	Decimal Hours
2	Mission Elapsed Time	C*12	D/HR: Min: Sec
3	Target ID	C*8	-
4	IPS Elevation (EL)	R*4	Degrees
5	IPS Cross-Elevation (XL)	R*4	Degrees
6	IPS ROLL (RL)	R*4	Degrees
7	HUT desired Slit Position Angle + 135° (to get Angle of Right Skewed Tracker)	R*4	Degrees



TABLE D-9. GIMBAL LIST-DIRECTED FILE FORMAT

<u>Word</u>	<u>Description</u>	<u>Data Type</u>	<u>Units</u>
1	Mission Elapsed Time	R*4	Decimal Hrs
2	STAR Name 1	C*4	-
3	STAR Name 2	C*4	-
4	Right Ascension of Boresight Star (M50)	R*4	Degrees
5	Declination of Boresight Star (M50)	R*4	Degrees
6	Right Ascension of Right Tracker (M50)	R*4	Degrees
7	Declination of Right Tracker (M50)	R*4	Degrees
8	IPS Elevation Angle (EL)	R*4	Degrees
9	IPS Cross-Elevation Angle (XL)	R*4	Degrees
10	IPS Roll Angle (RL)	R*4	Degrees
11	Celestial Roll Angle + 30°	R*4	Degrees
12	Celestial Roll	R*4	Degrees
13	Celestial Roll Angle -30°	R*4	Degrees
14	Orbiter Attitude Angle - Pitch	R*4	Degrees
15	Orbiter Attitude Angle - Yaw	R*4	Degrees
16	Orbiter Attitude Angle - Roll	R*4	Degrees
17	Reference Frame for Orbiter Attitude (1= Solar Inertial, 2 = Local Vertical, 3 - Inertial)	R*4	-
18-25	Blank Words	R*4	-

TABLE D-10. OBJECTIVE SUMMARY FILE FORMAT

<u>Word</u>	<u>Description</u>	<u>Data Type</u>	<u>Units</u>
1	Position Angle	R*4	Degrees
2	Objective Load Roll Angle	R*4	Degrees
3	Experiment Number	I*4	-
4	Type	I*4	-
5-6	Science Star Name (i.e., 8106-100) (Word 5 C*4) ( Word 6 C*4)	C*8	-
7	RAM50 (Right Ascension, mean-of-50)	R*4	Degrees
8	DEC M50	R*4	Degrees
9	RA MTOD (Right Ascension) Mission true-of-date)	R*4	Degrees
10	DEC MTOD	R*4	Degrees
11	Number of Boresight Guide Stars	I*4	-
12	Number of Right Tracker Guide Stars	I*4	-
13	Number of Left Tracker Guide Stars	I*4	-
14	MONTH	I*4	-
15	DAY Used in True-of-Date Calculations	I*4	-
16	YEAR	I*4	-
17	Boresight RA 2000	R*4	Degrees
18	Boresight DEC 2000	R*4	Degrees
19 1st Guide	Boresight Visual Magnitude	R*4	Degrees
20 Star	Boresight RA MTOD	R*4	Degrees
21 Data	Boresight DEC MTOD	R*4	Degrees
22-51 2nd thru 7th Boresight Guide Stars' Data			
52 1st Right	Right Tracker RA 2000	R*4	Degrees
53 Tracker	Right Tracker DEC 2000	R*4	Degrees
54 Guide	Right Tracker Visual Magnitude	R*4	-
55 Star	Right Tracker RA MTOD	R*4	Degrees
56 Data	Right Tracker DEC MTOD	R*4	Degrees
57-86 2nd thru 7th Right Tracker Guide Stars' Data			
87 1st Left	Left Tracker RA 2000	R*4	Degrees
88 Tracker	Left Tracker DEC 2000	R*4	Degrees
89 Guide	Left Tracker Visual Magnitude	R*4	-
90 Star	Left Tracker RA MTOD	R*4	Degrees
91 Data	Left Tracker DEC MTOD	R*4	Degrees
92-121 2nd thru 7th Left Tracker Guide Stars' Data			

TABLE D-11. OBJECTIVE LOADS FILE FORMAT

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
1	ST_MODE	Integer	<u>Stellar Mode Indicator.</u> For Stellar Mode, this should always be set to "1". For Solar or Earth mode, the value should be "0".
2	ST_IDOP_IDIN	Integer	<u>IDOP Mode Indicator</u> (used in Stellar Mode only). If objective is an IDOP function, which means that IPS is in the operational mode, the value should be set to "1". If not, the value should be "0". This corresponds to IDIN, which is the initial mode of operation, and also contains OSP calibration mode.
3	SO_MODE	Integer	<u>Solar Mode Indicator.</u> For Solar mode, the value is "1". For Stellar and Earth Modes; the value is "0".
4	SO_ROLCTR_LOS	Integer	<u>Roll type identifier for Solar Mode.</u> A "1" indicates a roll about the sun center, whereas a "0" indicates a roll about the current LOS. For Stellar and Earth Modes, this should be set to "0".
5	EA_MODE	Integer	<u>Earth Mode Indicator.</u> For Earth Mode, this should be set to "1". For Stellar and Solar Modes, this should be set to "0".
6	EA_LMLVM	Integer	<u>Earth Landmark Track Identifier.</u> This parameter is used only in Earth Mode to indicate either a Landmark Track objective (use a value of "1") or a Local Vertical objective (a value of "0"). For Stellar and Solar Modes, this should be set to "0".
7	FILLER_1	Array (1)	<u>Dummy Array.</u> It will be automatically filled in by OBJECT file generator program. (Leave out as input to file generator.)

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
8	OBJ_NO	Integer	<p><u>Objective number.</u> This parameter is used to identify the particular objective to be used for a given observation. It will be unique for each IPS attitude and orientation, and also will be unique for a given time period if the target is not inertially fixed, like planets, comets, etc. Note that the sun falls in this category. To determine when or if another objective is needed for the same target but for a different observing time, see item number 24 of this table and assess whether or not the guidestars will still appear in the FOV. The range of values is from 1 to 998.</p>
9	EXP_NO	Integer	<p><u>Experiment number.</u> This parameter is used to determine which experiment is selected. The range is from 1 to 5, with "1" always being assigned to the IPS itself (Boresight FHST LOS pointed to target defined in items 10-12). When another experiment is selected, the IPS will point the experiment LOS (defined by a DCM stored where the experiment LOS is to be pointed).</p>
10	ATT (1)	Array (7) Float Pt. (Scalar Number)	<p><u>Target Attitude.</u> In Stellar mode, this first element is the target Right Ascension (where the experiment LOS is to be pointed) in deg., relative to either Mission-True-of-Date (MTOD) System (0') or the Aries-Mean-of-Fifty (AM50) System (0"). The choice of reference system is dependent upon crew desires for a particular mission, as long as this reference is used throughout the objective loads (i.e. T_0_01, FHST_STARRA, etc.).</p> <p>In Solar Mode, this element represents target yaw, measured in arcsec, relative to the Solar Ecliptic System. (For Earth mode, see IPS-DS-MH-0049).</p>

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
11	(2)	Float Pt.	<u>Target Attitude (Continued)</u> . This is the same as item 10 (ATT (1)) except that in Stellar mode this represents target Declination in deg., and in Solar Mode this represents target pitch, in arcsec. (For Earth Mode, see IPS-DS-MH-0049).
12	(3)	Float Pt.	<u>Target Attitude (Continued)</u> . This is the same as item 10 (ATT (1)) except that in Stellar Mode this represents target Roll in deg., and in Solar Mode this also represents target Roll in deg. (+ 180°). This roll angle is defined as the angle from the meridian plane (Inertial or Solar Ecliptic Z-axis and selected experiment LOS) to the selected experiment Z-axis. A positive angle is defined as a positive rotation of the experiment (or boresight FHST) LOS from the meridian plane to the Experiment Z-axis. If Experiment 1 is selected, the body-fixed reference system to use is the IPS Platform (P) system. (For Earth Mode, see IPS-DS-MH-0049).
13	(4)	Float Pt.	<u>Target Attitude (Continued)</u> . Same as item 10 (ATT (1)).
14	(5)	Float Pt.	<u>Target Attitude (Continued)</u> . Same as item 11 (ATT (2)).
15	(6)	Float Pt.	<u>Target Attitude (Continued)</u> . Same as item 12 (ATT (3)).
16	(7)	Float Pt.	Not used in Stellar and Solar mode. The value should be set to "0".

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
17	SCAN_ROL	Float Pt.	<u>Scan Roll Offset</u> (in deg). This parameter sets the orientation of the scan frame in relation to inertial (or solar-fixed or Earth-fixed) space. A positive offset is a positive rotation about the Experiment (or IPS) LOS. If scanning is not desired for the particular objective, the value should be set to "0".
18	SCAN_LGTH	Float Pt.	<u>Scan Amplitude</u> (in arcmin). This indicates the length of a scan line, with each line being the same size. If scan is not used, the value should be "0".
19	SCAN_RATE	Float Pt.	<u>Scan Rate</u> (in arcmin/sec). This gives the desired scan rate of each line. Note that if scan is desired with optical hold, this rate must be below the max. FHST tracking rate capability. If scan is not used, the value should be 1.0E-6, due to software peculiarities.
20	SCAN_STEP	Float Pt.	<u>Scan Step</u> (in arcmin). This gives the desired distance between successive scan lines. If scan is not used, the value should be "0".
21	SCAN_LINE	Integer	<u>Number of scan lines desired.</u> If scan is not used, the value should be set to "0".
22	SCAN_FRAME	Integer	<u>Number of times the scan field should be scanned.</u> If scan is not used, the value should be set to "1".

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
23	SUN_POS	Array (13) Float. Pt.	<p><u>Sun position parameters.</u> For Stellar and Earth modes, these parameters should be left out as input to the OBJECT file generator.</p> <p>In Solar mode, this 13 parameter array provides data for interpolation of Sun position. See IPS-DS-MH-0011 for a complete definition of each of the parameters. Note that if these parameters are hand-calculated, it may be sufficient to calculate only 1 set of data for all objective loads, depending upon desired accuracy. However, if done by software it is recommended to use the time interval which defines the roll star(s) capability for the total time interval defining the Sun Position parameter calculations.</p>
24	DCM_T_0_01	Matrix(3,3) Float. Pt.	<p><u>Target Inertial to IPS Direction Cosine Matrix.</u> This parameter represents a transformation from the inertial reference used (AM50, MTOD, etc.) to the IPS Inertial reference (0) system. See IPS-DS-MH-0011 for calculation of DCM T_0_01. Note that this matrix, as defined for time "t", must not be in error more than 10 deg. by the time it is utilized during the mission, as it would cause instability of the Attitude Determination Filter (See param. ATT_CHECK in the MDP file AGAINs.)</p>
25	FHST_STARNO (1)	Array (3) Integer	<p>If Earth mode is selected, leave blank.</p> <p><u>Star-count parameter.</u> This parameter indicates the number of potential guidestars in the particular objective which are identified for the boresight FHST. For Stellar mode, this value can be 0, 1, or 2 for the special case of OSP calibration, or it can vary between 0 and 7 (inclusive) for operational objectives (IDOP).</p>

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
25 (cont)			For Solar mode, this value is always 1, since the Sun will always be in the tracker FOV.
26	(2)	Integer	For Earth mode this parameter is not used, and should be left blank.  Star-count parameter (Continued). For Stellar mode, this is the same as item 25 (FHST STARNO(1)) except for the right skewed FHST. For Solar mode, this value can either be 0 or 1. This is not used in Earth mode, and should be left blank.
27	(3)	Integer	Star-count parameter (Continued). This is the same as item 26 (FHST STARNO(2)) except that it is for the left skewed tracker.
28	FHST STARRA (1,X)	Matrix(3,7) Array (7) Float. Pt.	Star Right-Ascension. For Stellar mode given an IDIN or IDOP objective, this 7 element array will contain the right-ascension of each potential guidestar (in radians) identified for the boresight tracker, resolved in an inertial (MTOD, AM50, etc.) reference system. If there are less than 7 stars as defined by item 25 above, the remaining elements in this array should be set to zero. If there is more than 1 star identified, the array should be organized such that the brightest star is first and dimmest star is last. In the OSP calibration mode, elements 1 and 2 are the right-ascension of the bright star and dim star respectively in the boresight FHST FOV.



TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
28 (cont)			Elements 3 and 4 are the expected "Y" and "Z" positions (in radians) respectively of the bright star in the boresight FHST FOV, resolved in that tracker's geometric (M) system. Elements 5 and 6 are the same as elements 3 and 4 except they pertain to the dim star. Element 7 should be left blank.
29	(2, X)	Array (7) Float. Pt.	For Solar and Earth modes, all 7 elements should be left blank.  Star Right-Ascension (Continued). For Stellar mode, this is the same as item 28 (FHST_STARRA (1,X)) except everything pertains to the right-skewed tracker. For Solar mode, element 1 will contain the star right-ascension (in radians) for the guidestar in the right tracker, resolved in an inertial (MTOD, AM50, etc.) reference system. If no star has been identified for the right tracker as defined by item 26 (FHST_STARNO(2)), then this should be left blank. The other 6 elements should be left blank.
30	(3, X)	Array (7) Float. Pt.	For Earth mode, all 7 elements should be left blank.  Star Right-Ascension (Continued). This is the same as item 29 (FHST_STARRA (2,X)) except that it is for the left skewed tracker.

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
31	FHST_STARDEC (1,X)	Matrix (3,7) Array (7) Float. Pt.	Star Declination. For Stellar mode given an IDIN or IDOP objective, this 7 element array will contain the declination of each potential guidestar (in radians) identified for the boresight tracker, resolved in an inertial (MTOD, AM50, etc.) reference system. If there are less than 7 stars as defined by item 25 above, the remaining elements in this array should be set to zero. If there is more than 1 star identified, the array should be organized such that the brightest star is first and dimmest star is last. In the OSP calibration mode, elements 1 and 2 are the declinations of the bright star and dim star respectively in the boresight FHST FOV. Elements 3 through 7 should be left blank.
32	(2,X)	Array (7)	For Solar and Earth modes, all 7 elements should be left blank.
33	(3,X)	Array (7) Float. Pt.	Star Declination (Continued). This is the same as item 31 (FHST_STARDEC (1,X)) except that it is for the right skewed tracker.  Star Declination (Continued). This is the same as item 31 (FHST_STARDEC (1,X)) except that it is for the left skewed tracker.

TABLE D-11. (Continued)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
34	FHST CR_CMD (1,X)	Matrix (3,7) Array (7) Integer	<p>Star Countrates. For Stellar mode given an IDIN or IDOP objective, this 7 element array will contain the star magnitude (expressed as a countrate) for each potential guidestar identified for the boresight tracker. In IDOP if there are less than 7 stars defined by item 25 above, the remaining elements in this array should be set to zero. In IDIN if there are no stars identified for a given objective, the first element should be set to 32767, with the rest of the elements blank.</p> <p>Note that conversion between magnitude and countrate is FHST, position, and star temperature dependent; the conversion equations are given in IPS-SED-04, Vol. 3, FHST User's Manual-FMX-Specific Parameters.</p> <p>In Solar mode, element 1 should contain the countrate of the Sun, with all other elements blank. The Sun countrate is FHST model and Sun beam splitter-dependent, and is found in IPS-SED-04, Vol. 3 for the particular boresight FHST.</p> <p>In Earth mode, leave all elements blank.</p>

TABLE D-11. (Concluded)

ITEM NUMBER	STRUCTURE ELEMENT	DATA TYPE	PARAMETER DESCRIPTION
35	(2 X)	Array (7) Integer	<p>Star Countrates (Continued). For Stellar mode, this is the same as item 34 (FHST_CR_CMD(1, X)) except relative to the right skewed tracker.</p> <p>For Solar mode, element 1 of the 7 element matrix should contain the star countrate of the guidestar identified for the right skewed tracker; with all other elements left blank. If there is no star identified for the right tracker for a particular objective, element 1 should be set to 32767 with the remaining elements blank. (This allows the tracker to continually be in search mode so that it can send housekeeping data to the Subsystem Computer.)</p> <p>In Earth mode, leave all elements blank.</p>
36	(3, X)	Array (7) Integer	<p>Star Countrates (Continued). This is the same as item 35 (FHST_CR_CMD(2, X)) except relative to the left skewed tracker.</p> <p>NOTE: FOR MORE INFORMATION, SEE IPS-DS-SP-109.2, SPECIFICATION OF COMPOOLS (PART 2: COMPOOL COBJ), IPS-DS-MH-0049, OBJGEN SOFTWARE USERS MANUAL, IPS-DS-MH-0011, HOW TO GENERATE MISSION DEPENDENT PARAMETERS, OR IPS-SED-04, VOLUME 3, FHST USER'S MANUAL-FMX-SPECIFIC PARAMETERS.</p>

TABLE D-12. MMU LOAD FILE FORMAT

<u>WORD #</u>	<u>NAME</u>	<u>DESCRIPTION</u>	<u>DATA TYPE</u>
1	NOB	Number of Bytes on objective load (currently NOB=372)	I*4
2-37		(Same as objective Load File Format as shown in Table D-11)	
38		Check sum for MITRE computer	

## REFERENCES

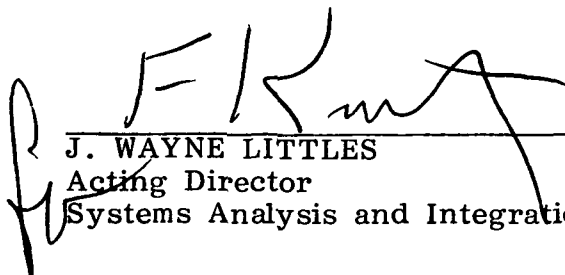
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APPROVAL

IPS GUIDESTAR SELECTION FOR STELLAR MODE (ASTRO)

By Larry Mullins and Lewis Wooten

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



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